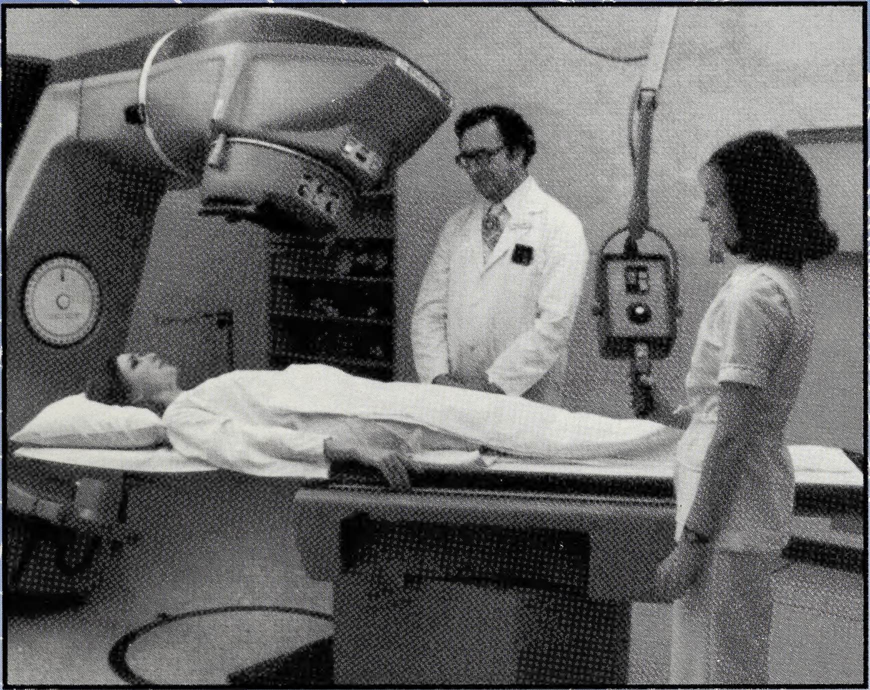
PHYSICS 30



Module 8

Physics for Life: Assessing Risks and Benefits

Distance Learning

Alberta
EDUCATION

Physics 30

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Physics for Life: Assessing Risks and Benefits

Alberta EDUCATION

Distance Learning

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Students	✓
Teachers (Physics 30)	✓
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Other	

Physics 30
Student Module
Module 8
Physics for Life: Assessing Risks and Benefits
Alberta Distance Learning Centre
ISBN 0-7741-0974-2

Cover Photo: CANADIAN NUCLEAR ASSOCIATION

Welcome to Module 8!

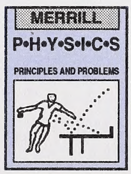
We hope you'll enjoy your study of *Physics for Life: Assessing Risks and Benefits.*

To make your learning a bit easier, watch the referenced videocassettes whenever you see this icon.

You also have the option of viewing laser videodisc clips when you see the bar codes like this one.

Frame 4850A

When you see this icon, study the appropriate pages in your textbook.



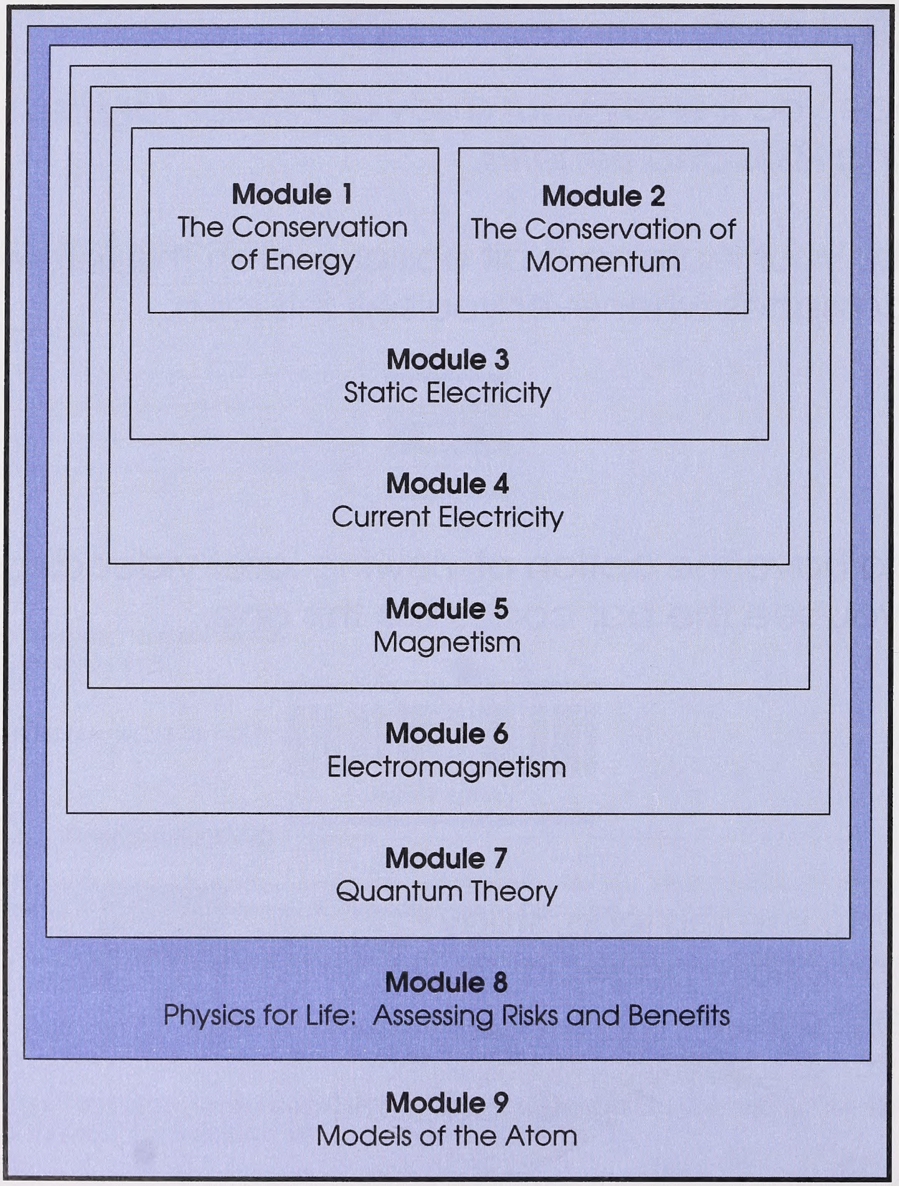
Good Luck!

Course Overview

This course contains nine modules. The first two modules develop the conservation laws of energy and momentum. The conservation of energy is at the heart of the entire course. Modules 3 through 9 build one upon the other and incorporate the main ideas from the preceding modules.

The module you are working in is highlighted in a darker colour.

PHYSICS 30



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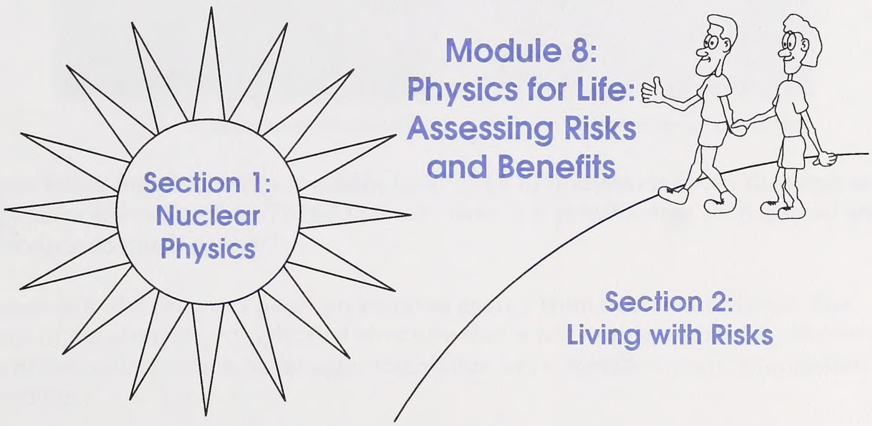
OVERVIEW

So far the holiday has been great. The people that you are visiting are taking you to all the sights in southern Ontario. As you drive along the highway, you pass a large facility on the shore of Lake Ontario. When you ask what the facility is, the driver says, "Oh, that's the nuclear generating station."

For some reason you feel strange as you continue to drive by the plant. You have never seen a nuclear power generating station before, and many different and unconnected ideas begin to enter your mind. You wonder if it's safe to drive here, but the presence of all the other cars on the highway suggests that the risks are probably low. Just the same, you still feel strange.

Why does nuclear energy tend to trigger this kind of response in people when they first encounter this technology? Do the experts who live and work in these facilities feel the same way? The sun and the stars are powered by nuclear energy. Why don't these things evoke the same response?

In this module you will explore the answers to these questions and others like them. You will begin by learning the basics of nuclear physics. In the second section of this module, you will consider how people determine the risks associated with a variety of hazards in modern living, including nuclear energy.



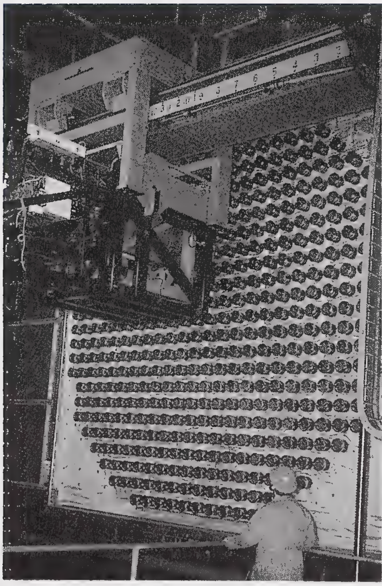
Evaluation

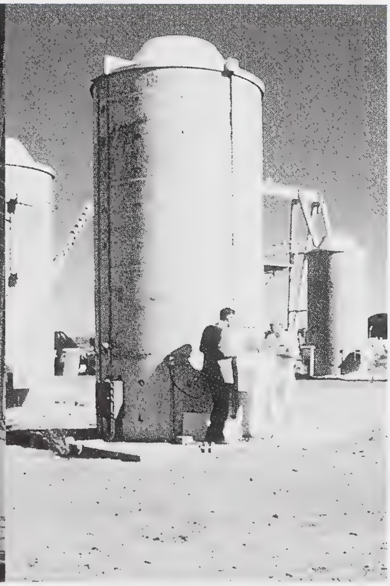
Your mark in this module will be determined by your work in the Assignment Booklet. You must complete all assignments. In this module you are expected to complete two section assignments. The mark distribution is as follows:

Section 1 Assignment	60 marks
Section 2 Assignment	40 marks
TOTAL	**100 marks**

Section

1 Nuclear Physics





CANADIAN NUCLEAR ASSOCIATION CANADIAN NUCLEAR ASSOCIATION

Did you know that the energy available from 23 kg of uranium is about the same as the energy from 400 t of coal or 270 000 L of oil? How is it possible that such a small amount can produce so much energy?

The answer to the previous question involves energy from nuclear reactions. The nucleus of the atom is a complicated structure that is not fully understood. However, years of theoretical research and experimentation have provided some information about the nucleus.

In this module you will have an opportunity to reassess your initial estimate of the risks associated with nuclear power. You will begin by learning some of the basics about nuclear physics and how nuclear energy can be used to generate electricity. This will be the focus of Section 1.

In Section 2 you will examine the whole topic of determining risk. You will see how these ideas about risk apply to nuclear energy.

Activity 1: What Is Risk?

Do you think that you lead a risky life? Do your friends or your family take risks on a daily basis? To help you organize your thoughts on these questions, complete the following survey about risks taken in daily life.

1. Copy the following list of hazards into your notebook. Rank the hazards in the order of their level of risk to the citizens of Canada. Indicate the hazard with the greatest risk with a 1 and the hazard with the least risk with a 7. There are no right or wrong answers to this question. The idea is to get you thinking about risks.

Hazard

nuclear power	home appliances
motor vehicles	food preservatives
cigarette smoking	skiing
non-nuclear power	

The first thing that you should realize after completing question 1 is that everything has a level of risk associated with it. Risk is an accepted part of life. Even if you spent your whole life in bed and never left your home, you would face the risk of poor health from lack of exercise.

What hazard on the list do you think creates the most disagreements between experts and society? If you said "nuclear power", you are right.

2. Why do you think that the disagreements about nuclear power are so strong? What do people base their estimates of risk on for nuclear power? On what did you base your estimate of risk?

It is ironic that the only physics equation that most people know is $E = mc^2$. This equation can be readily applied to nuclear physics, yet the physics of nuclear energy is one topic that most people know absolutely nothing about.

Check your answers by turning to the Appendix, Section 1: Activity 1.

In this section you will learn about the discovery of radioactivity and you will learn how to use an equation to calculate the energy from simple nuclear reactions. In the last activity you will learn how nuclear energy can be used to generate electricity.

Activity 2: Radioactivity

The word *radioactivity* causes many people to immediately start thinking about risks and hazards. Surprisingly, radiation is a natural phenomenon that has been part of human experience since the beginning of time. However, since human senses cannot detect radiation, it is only in the last hundred years that the proper technology has existed to study it. In the next part of this activity you will learn about the discovery of radioactivity by examining a number of short programs from the video series called *Nuclear Physics*.

Familiarize yourself with the following questions about the main ideas from the video program called *The Discovery of Radioactivity*. You will have to stop the tape periodically so that you can answer the questions.

1. Faraday discovered that if a tube containing two high-voltage electrodes was evacuated, a mysterious glow appeared opposite the negative electrode. What name was given to these mysterious emissions?

2. What properties were demonstrated by the rays discovered by Faraday?

3. Roentgen also discovered a new type of ray emitted by a high-voltage tube. Copy the following headings into your notebook. Be careful to leave enough space for your answers. Compare the rays discovered by Roentgen with those disovered by Faraday by completing the chart.

	Faraday's Rays	Roentgen's Rays
Name of Rays		
Could the rays be bent by electric or magnetic fields?		
Were these rays nuclear radiation?		

4. Henri Becquerel studied materials that are fluorescent (they emit visible light when exposed to sunlight). What was the original purpose of his experiment?

5. Becquerel's experiment eventually led him to test a piece of rock containing uranium. At first he thought that the rock was emitting x-rays, but he later discovered that the rock was emitting something different. What was the main difference between Becquerel rays and x-rays?

6. Marie Curie discovered that thorium, polonium, and radium also emit Becquerel rays. What name did she give to the ability of substances to spontaneously produce radiation?

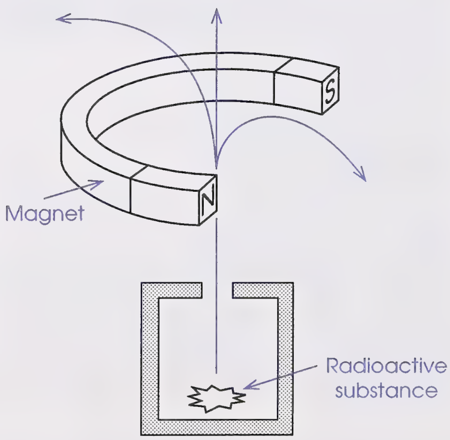
When the program ends, stop the tape.

Check your answers by turning to the Appendix, Section 1: Activity 2.

The next program outlines how the properties of Becquerel rays were discovered. Familiarize yourself with the following questions about the main ideas from the program called *The Properties of Becquerel Rays*. You will have to stop the tape periodically so that you can answer the questions.

7. Using a device designed by the Curies, Rutherford studied the ability of Becquerel rays to penetrate sheets of aluminum foil. What did Rutherford observe and what did he conclude from these observations about Becquerel rays?

8. Once gamma rays were discovered, much experimentation was done to determine the properties of the three types of radiation. The following diagram represents some of these results. Copy this diagram into your notebook. Be careful to leave enough space to record your answers. Complete the diagram by labelling the three types of radiation shown.



9. Use principles from earlier in the course to explain why the three types of radiation travel along the paths indicated in the previous diagram.

10. Copy the following headings into your notebook. Complete the comparison chart for the three types of radiation. You will have to adjust the size of your chart according to the length of your answers.

Comparing Three Types of Radiation			
	Alpha	**Beta**	**Gamma**
Type of Particle			
Relative Mass			
Speed			
Penetrating Ability			
Description and Explanation of Cloud Chamber Tracks			

When the program ends, stop the tape.

Check your answers by turning to the Appendix, Section 1: Activity 2.

You now know what the three types of radiation are and how they behave. Why do they occur? You will learn the answer to this question in the next video program.

Familiarize yourself with the following questions about the main ideas from the video program called *Natural Transmutations*. You will have to stop the program periodically so that you can answer the questions.

11. What does the term *transmutation* mean?

12. What particle determines the identity of an atom?

13. Which particle can vary in number, forming isotopes of an element?

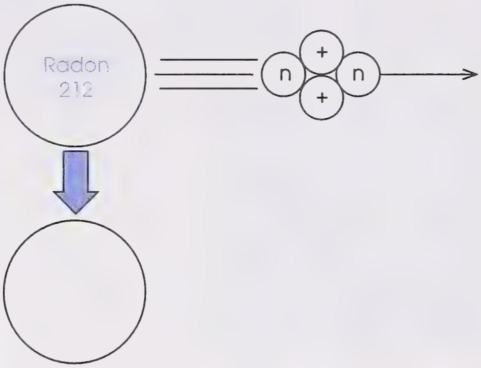
14. Label the notations for protons and neutrons in the symbol for lithium.

$$^{7}_{3}\mathrm{Li}$$

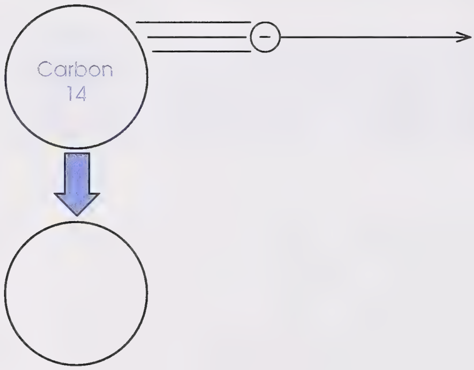
15. What is the main difference between a chemical reaction and radioactive decay?

16. The three basic types of radioactive decay are alpha decay, beta decay, and gamma decay. Copy the following diagrams into your notebook. Be careful to leave enough space to record your answers. Complete the diagrams by adding the necessary labels and explanations to each of the diagrams to illustrate each type of radiocative decay.

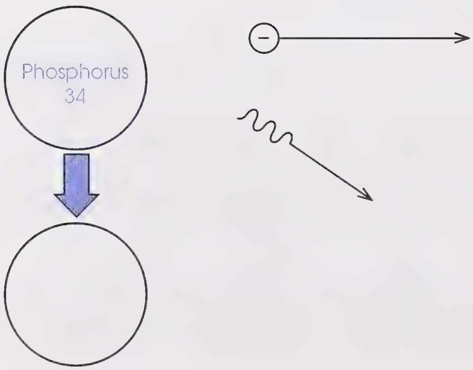
a. $^{212}_{86}\text{Rn}$



b. $^{14}_{6}\text{C}$



c. $^{34}_{15}\text{P}$



17. In question 16. a. you considered the decay of the gas radon 212 to polonium 208. How long would it take half the atoms in a sample of radon 212 to decay to polonium 208?

18. Define *half-life*.

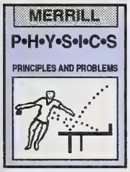
19. What is the half-life for each of the following isotopes?

    a. polonium 214
    b. actinium 225
    c. plutonium 236
    d. uranium 238

When the program ends, stop the tape.

Check your answers by turning to the Appendix, Section 1: Activity 2.

So far you've been representing radioactive decay by drawing pictures. Another way to represent radioactive decay is to write equations that describe the reaction that is taking place. To learn how these equations can be used, read from the bottom of page 619 to the top of page 621 in your textbook. Be sure to carefully study the Example Problems that are provided.



20. Do Practice Problems 5 to 8 on page 621 of your textbook.

Check your answers by turning to page 686 of your textbook.

Now you will have an opportunity to learn more about half-lives through an investigation.

PATHWAYS

If you are working with a group of students, do Part A.
If you are working alone, do Part B.

MERRILL P•H•Y•S•I•C•S PRINCIPLES AND PROBLEMS

Science Skills

- ☐ A. Initiating
- ☑ B. Collecting
- ☑ C. Organizing
- ☑ D. Analysing
- ☑ E. Synthesizing
- ☐ F. Evaluating

Part A

Investigation: A Group of Students Simulate Half-Life

Turn to page 623 of your textbook. You are going to do the lab called Heads Up. This will simulate a radioactive decay in which you collect the data.

Follow the instructions given on page 623 and do the lab.

End of Part A

Part B

Investigation: One Student Simulates Half-Life

Purpose

You will simulate a radioactive decay in which you collect your own data.

Materials

- 100 pennies
- shoe box

Procedure

- Set up a data table where you can record a coin toss number versus the number of "heads" that appear.
- Place all your coins heads up in a box. Shake the box.
- Record the number of heads that occur. Remove the coins that were tails up. Shake the box again.
- Record the number of heads that occur. Remove the coins that were tails. Shake the box again.
- Repeat the previous step two more times.

End of Part B

Analysis and Conclusions

MERRILL P•H•Y•S•I•C•S PRINCIPLES AND PROBLEMS

Whether you did Part A or Part B, the Analysis questions on page 623 of your textbook will help you to interpret your data.

21. Do Analysis question 1 on page 623 of your textbook. Record your answer on standard graph paper with 1-cm squares. Be sure to leave ten squares on the horizontal axis and eight squares on the vertical axis.

22. Do Analysis question 2 on page 623 of your textbook.

23. To see how these ideas can be applied to radioactive materials kept by hospitals, do Applications question 1 on page 623 of your textbook.

Check your answers by turning to the Appendix, Section 1: Activity 2.

The solution to the last question may have been easy to understand, but you will probably agree that it is a time-consuming and cumbersome technique.

An Equation for Half-Life Calculations

The following example will illustrate an equation that is a valuable time saver.

Example

A prehistoric mammal eats plant material that contains radioactive carbon 14. What fraction of the carbon 14 will still be active after six half-lives?

Solution

Charting six half-lives will give you the answer.

Percentage of Active Carbon 14

		$\times\frac{1}{2}$	$\times\frac{1}{2}$	$\times\frac{1}{2}$	$\times\frac{1}{2}$	$\times\frac{1}{2}$	$\times\frac{1}{2}$
Percentage remaining →	100	50	25	12.5	6.25	3.125	1.5625
Half-lives →		One	Two	Three	Four	Five	Six

The main idea behind this solution is to multiply the original amount of carbon 14 by $\frac{1}{2}$ six times.

$$\begin{aligned}\text{amount that is still active} &= (\text{original amount}) \times \left(\frac{1}{2} \times \frac{1}{2} \times \frac{1}{2} \times \frac{1}{2} \times \frac{1}{2} \times \frac{1}{2}\right) \\ &= (\text{original amount}) \times \left(\frac{1}{2}\right)^6 \\ &= (100\%) \times (0.015\,625) \\ &= 1.5625\% \\ &= 1.56\%\end{aligned}$$

Calculating $\left(\frac{1}{2}\right)^6$ may require you to refer to the instruction manual for your calculator. In most cases the button that you would use would be $\boxed{y^x}$. If this is the button that performs this function on your calculator, the sequence for calculating $\left(\frac{1}{2}\right)^6$, which is the same as $(0.5)^6$, would be as follows:

$$\boxed{0}\ \boxed{.}\ \boxed{5}\ \boxed{y^x}\ \boxed{6}\ \boxed{=}$$

Try the calculation on your calculator until you get the correct answer.

To simplify things further, this equation can be represented by the following variables.

$$\boxed{N = N_o \left(\frac{1}{2}\right)^n}$$

n: Number of half-lives that have passed

N_o: Original amount of sample that was active

N: Amount of sample that is still active

As long as you keep the variables straight, this equation makes things much easier. Here's how the example could be solved.

$N = ?$

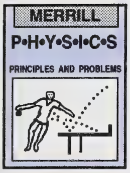
$N_o = 100\%$

$n = 6$

$$\begin{aligned}N &= N_o \left(\frac{1}{2}\right)^6 \\ &= (100\%)\left(\frac{1}{2}\right)^6 \\ &= 1.56\%\end{aligned}$$

24. Redo question 23 using this new equation. Check with the Appendix to be sure that you get the correct answer.

Check your answers by turning to the Appendix, Section 1: Activity 2.



25. To see how half-life calculations can be applied to different isotopes, do Practice Problems 9 through 11 on page 622 of your textbook.

Check your answers by turning to page 686 of your textbook.

Activity 3: Calculating Energy in Nuclear Reactions

The main idea behind the energy that is released through a nuclear reaction is that mass and energy are really just two different forms of the same thing. Albert Einstein expressed this idea in his most famous equation.

$$\boxed{E = mc^2}$$

Energy equivalent (energy that is released from the conversion of the change in mass) → E

Change in mass (amount of mass that is converted into energy) → m

Speed of light squared → c^2

$c = 3.00 \times 10^8 \ \text{m/s}$

$c^2 = 9.00 \times 10^{16} \ \text{m}^2/\text{s}^2$

One thing that immediately becomes evident is that the exceptionally large value of c^2 means that small amounts of mass can be converted into huge amounts of energy. Consider the following example that gives the energy produced from the fission of one uranium 235 atom.

fission – complex nuclei break apart into smaller components and release energy

Example

The fission of one uranium 235 atom causes 4.2×10^{-28} kg of mass to be converted into energy. Calculate the energy that is released.

$$\begin{aligned} E &= mc^2 \\ &= \left(4.2 \times 10^{-28} \ \text{kg}\right)\left(3.00 \times 10^8 \ \text{m/s}\right)^2 \\ &= 3.8 \times 10^{-11} \ \text{J} \end{aligned}$$

This amount of energy may seem small, but remember that it is produced by just one atom of uranium 235. Consider the result if only 1 mol, or 235 g, of these atoms underwent fission.

$$\begin{aligned} E &= (\text{energy released per atom}) \times (\text{number of atoms in 1 mol}) \\ &= (3.8 \times 10^{-11}\ \text{J/atom}) \times (6.022 \times 10^{23}\ \text{atoms}) \\ &= 2.3 \times 10^{13}\ \text{J} \end{aligned}$$

This is a huge amount of energy from a small amount of uranium. It is important to realize that although only about 0.1%, or 0.25 g, of the uranium 235 sample was actually converted into energy, the energy released was tremendous. The following comparison may help you understand how much energy this is.

One mole (235 g) of ${}^{235}_{92}\text{U}$ undergoing fission releases 2.3×10^{13} J of energy. This is equivalent to the amount of energy released by exploding $4\frac{1}{2}$ kt of TNT.

Energy from an Unstable Nucleus

In the previous example, the mass of the reaction products is less than the mass of the initial reactants. This is always the case for an unstable nucleus. Mass is converted into energy that is released during radioactive decay.

1. When carbon 14 $\left({}^{14}_{6}\text{C}\right)$ decays to nitrogen 14 $\left({}^{14}_{7}\text{N}\right)$, the total mass of the initial reactants is $2.325\,28 \times 10^{-26}$ kg, while the mass of the final products is $2.325\,26 \times 10^{-26}$ kg.

    a. Calculate the energy that would be released from this decay.

    b. What type of radiation is emitted in this case? Explain your answer.

2. Cobalt 60 $\left({}^{60}_{27}\text{Co}\right)$ emits a gamma ray with an energy of 2.13×10^{-13} J. Calculate the equivalent mass that was converted to create the gamma radiation.

3. Neon 23 $\left({}^{23}_{10}\text{Ne}\right)$ has a mass of $3.818\,32 \times 10^{-26}$ kg and it decays to sodium 23 $\left({}^{23}_{11}\text{Na}\right)$, which has a mass of $3.817\,53 \times 10^{-26}$ kg.

    a. Calculate the energy that is released from this decay.

b. What type of radiation is emitted in this case? Explain your answer.

Check your answers by turning to the Appendix, Section 1: Activity 3.

Energy Considerations in a Stable Nucleus

The previous questions illustrate the situation that occurs when an unstable nucleus spontaneously converts mass into energy, resulting in radioactive decay. When the nucleus is stable, it is the reverse concept that applies. The mass of the stable nucleus is less than the mass of the component parts. The difference in the two masses is called the **mass defect**. The resulting energy from this loss in mass is released as radiation when the nucleus forms.

mass defect – the difference between the mass of a nucleus and the mass of its component parts

Example

Use the following data to calculate the mass defect and the corresponding energy that is released when a helium $\left({}^{4}_{2}\text{He} \right)$ nucleus is formed.

$$\text{mass of one proton} = 1.673\,53 \times 10^{-27}\ \text{kg}$$
$$\text{mass of one neutron} = 1.674\,92 \times 10^{-27}\ \text{kg}$$
$$\text{mass of helium nucleus} = 6.646\,46 \times 10^{-27}\ \text{kg}$$

Step 1: Calculate the total mass of the component parts.

$$\begin{aligned}\text{total mass} &= 2(\text{mass of one proton}) + 2(\text{mass of one neutron})\\ &= 2\left(1.673\,53 \times 10^{-27}\ \text{kg}\right) + 2\left(1.674\,92 \times 10^{-27}\ \text{kg}\right)\\ &= \left(3.347\,06 \times 10^{-27}\ \text{kg}\right) + \left(3.349\,84 \times 10^{-27}\ \text{kg}\right)\\ &= 6.696\,90 \times 10^{-27}\ \text{kg}\end{aligned}$$

Step 2: Calculate the mass defect.

$$\begin{aligned}\text{mass defect} &= (\text{mass of component parts}) - (\text{mass of nucleus})\\ &= \left(6.696\,90 \times 10^{-27}\ \text{kg}\right) - \left(6.646\,46 \times 10^{-27}\ \text{kg}\right)\\ &= 5.044 \times 10^{-29}\ \text{kg}\end{aligned}$$

Step 3: Calculate the corresponding energy.

$$\begin{aligned} E &= mc^2 \\ &= \left(5.044\times10^{-29}\ \text{kg}\right)\left(3.00\times10^{8}\ \text{m/s}\right)^2 \\ &= 4.54\times10^{-12}\ \text{J} \end{aligned}$$

fusion – nuclei join to form a larger nucleus, usually with the release of energy

The amount of energy calculated in the previous example would be released if the component parts were brought together to form a helium nucleus. This is called **fusion**. Fusion is the reaction that occurs within the sun. The energy that sustains life on Earth is a consequence of nuclear fusion!

binding energy – the energy required to separate a nucleus into its component parts

If you wanted to reverse the process and break the helium nucleus into its component parts, you would have to add 4.54×10^{-12} J. In this case the energy is called the **binding energy**. The important thing to realize is that the binding energy is not something that the nucleus has, but rather it is something that the nucleus lacks. For this reason, the binding energy is often described as a negative amount of energy.

The following questions will give you practice with Einstein's equation as it applies to mass defect and binding energy.

4. Deuterium $\left({}^{2}_{1}\text{H}\right)$ is an isotope of hydrogen which is created by the fusion of a neutron and a proton. Use the data provided to calculate the mass defect and the binding energy for deuterium.

   mass of a neutron $= 1.674\,92\times10^{-27}$ kg

   mass of a proton $= 1.673\,53\times10^{-27}$ kg

   mass of a deuterium nucleus $= 3.344\,32\times10^{-27}$ kg

5. Tritium $\left({}^{3}_{1}\text{H}\right)$ is another radioactive isotope of hydrogen. The mass of a tritium nucleus is $5.008\,26\times10^{-27}$ kg. Use the data for neutrons and protons that is provided in the previous question to calculate the mass defect and binding energy for tritium.

6. The energy released in a fusion reaction could be used as a source of energy on Earth. One possible reaction is the combination of deuterium $\left({}^{2}_{1}\text{H}\right)$ and tritium $\left({}^{3}_{1}\text{H}\right)$ to create helium $\left({}^{4}_{2}\text{He}\right)$, a neutron, and lots of energy.

The following reaction equation summarizes this reaction.

$$^{2}_{1}\text{H} + ^{3}_{1}\text{H} \rightarrow ^{4}_{2}\text{He} + ^{1}_{0}\text{n} + \text{energy}$$

Use the following data to calculate the energy that is released.

$$\text{mass of a deuterium nucleus} = 3.344\,32 \times 10^{-27}\ \text{kg}$$

$$\text{mass of a tritium nucleus} = 5.008\,26 \times 10^{-27}\ \text{kg}$$

$$\text{mass of a helium nucleus} = 6.646\,46 \times 10^{-27}\ \text{kg}$$

$$\text{mass of a neutron} = 1.674\,92 \times 10^{-27}\ \text{kg}$$

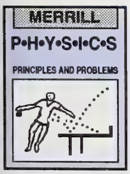
Check your answers by turning to the Appendix, Section 1: Activity 3.

How is it possible to bring protons together in the nucleus of an atom? Since protons are both positive, shouldn't they repel each other? Shouldn't the force of electric repulsion push them apart?

The fact that the protons in a nucleus don't fly apart has led to the conclusion that some other force is at work within the nucleus. Since this force is stronger than the force of electric repulsion, it is called the strong nuclear force. The strong nuclear force is an attractive force that holds protons together and is also thought to be responsible for holding the neutrons together.

strong nuclear force – a short-range force that attracts the nucleons to hold the nucleus together

The weak nuclear force (so named because it is much weaker than the strong nuclear force) is also present in the nucleus and reveals itself in certain types of radioactive decay.



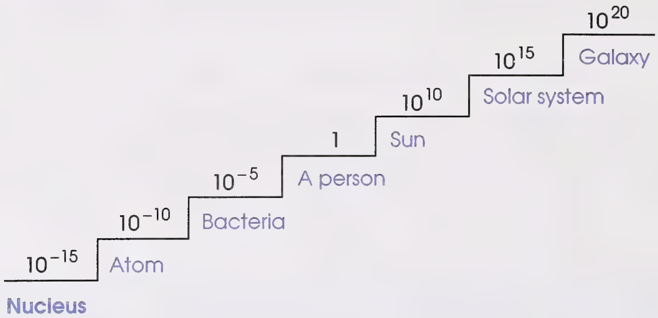
To summarize what you have learned so far in this activity, read pages 640 to 642 in your textbook. Your textbook measures mass in atomic mass units and energy in mega electron volts (MeV). Don't let these different units distract you – the physics is still the same.

7. Does the strong nuclear force between two protons act differently than it does between two neutrons?

8. The strong nuclear force is sometimes referred to as a short-range force. Explain why.

9. Which isotope has the most negative binding energy per nucleon?

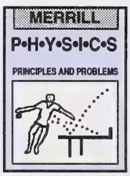
The textbook mentions that the strong nuclear force acts over an extremely small distance that is about equal to the radius of one proton, or about 1.3×10^{-15} m. Consider how small this number really is. The following chart represents the range of sizes, measured in metres, of some familiar objects.



10. If a grape (diameter 10 mm), which represents the **nucleus** of an atom, is placed at home plate in a baseball diamond, where would the outer edge of the atom be? Use the preceding chart to help determine your answer.

Check your answers by turning to the Appendix, Section 1: Activity 3.

Activity 4: Using Nuclear Energy



The energies that you calculated in the previous activity have many useful applications. To learn how radioactivity is used in medicine, read pages 643 to 644 of your textbook.

1. What is a positron?

2. What are tracer isotopes used for?

3. What kind of information can be provided by a PET scanner?

4. The cover of this module booklet shows a person undergoing cancer therapy. The machine uses the radiation from cobalt 60 $\left({}^{60}_{27}\text{Co} \right)$.

   a. Why does the machine have to be able to rotate to different positions?

   b. What type of radiation is emitted to treat the cancerous tissue?

Nuclear energy is also used to sterilize medical products. Everything from surgical gloves, scalpel blades, and syringes can be prepackaged and then passed through a large radioactive cobalt 60 source. The irradiation kills all bacteria, viruses, and other living organisms that could threaten the sterile environment of an operating room. This method is particularly useful for heat-sensitive materials which would melt if a high-temperature, conventional method was used.

Food can also be treated with irradiation to kill bacteria and other infestations. To learn more about this process, turn to the article called "Why Food Irradiation?" in the Appendix.

5. What three things does food irradiation do to help preserve food?

6. Is irradiated food radioactive?

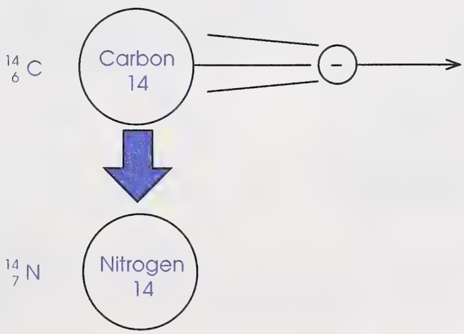
The irradiation of food is a controversial topic. You may have heard about protests over the use of this process. However, you'll likely hear the most protests about the use of nuclear energy to generate electricity. You'll learn the basic physics of the process in the next part of this activity by examining a number of short programs from the video series called *Nuclear Physics*.

Familiarize yourself with the following questions about the main ideas from the video program called *Energy from the Nucleus*. You will have to stop the tape periodically so that you can answer the questions.

7. Whose famous equation stated that mass and energy are two forms of the same thing? What is the equation?

8. If it was possible to completely convert one drop of gasoline into energy, for how long could a car be powered?

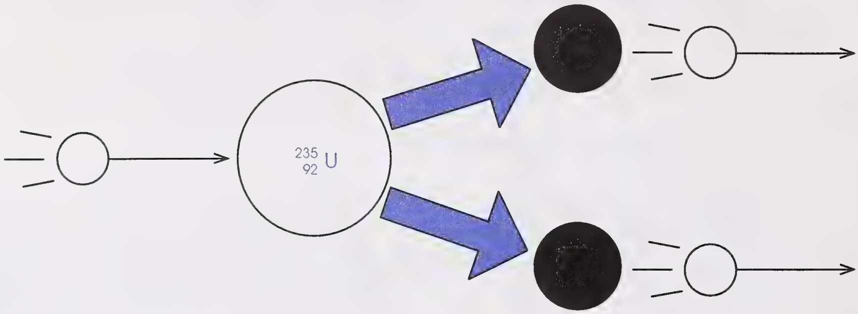
9. The following diagram represents the beta decay of carbon 14 to nitrogen 14. Copy the diagram into your notebook. Be careful to leave enough space to record your answers.



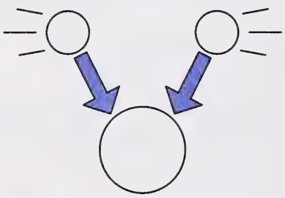
a. Label the diagram in your notebook to show which parts have less mass.

b. Label the diagram in your notebook to show what happened to the missing mass.

10. Copy the following diagram into your notebook. Be careful to leave enough space to record your answers. Complete the diagram by labelling the key ideas of fission that were proposed by Frisch and Meitner.



11. Copy the following diagram into your notebook. Be careful to leave enough space to record your answers. Complete the diagram by adding labels to illustrate the main ideas of fusion.



When the program ends, stop the tape.

Check your answers by turning to the Appendix, Section 1: Activity 4.

The next program will outline the basic ideas involved in using the huge amount of energy from fission to produce electric energy.

Familiarize yourself with the following questions about the basic ideas in the program called *Electrical Energy from Fission*. You will have to stop the program periodically so that you can answer the questions.

12. Why doesn't a chain reaction result when fission occurs in a sample of uranium ore?

13. What essential characteristics must the neutrons have to cause fission in uranium 235?

14. What role does heavy water play in the fission process, and why is it preferable to ordinary water?

15. What essential safety feature is found in nuclear reactors to ensure that too many neutrons don't cause too much energy to be released?

16. Explain what causes the water to become super-heated in the pressurized reactor vessel.

17. Does the super-heated water create the steam to turn the turbines?

When the program ends, stop the tape.

Check your answers by turning to the Appendix, Section 1: Activity 4.

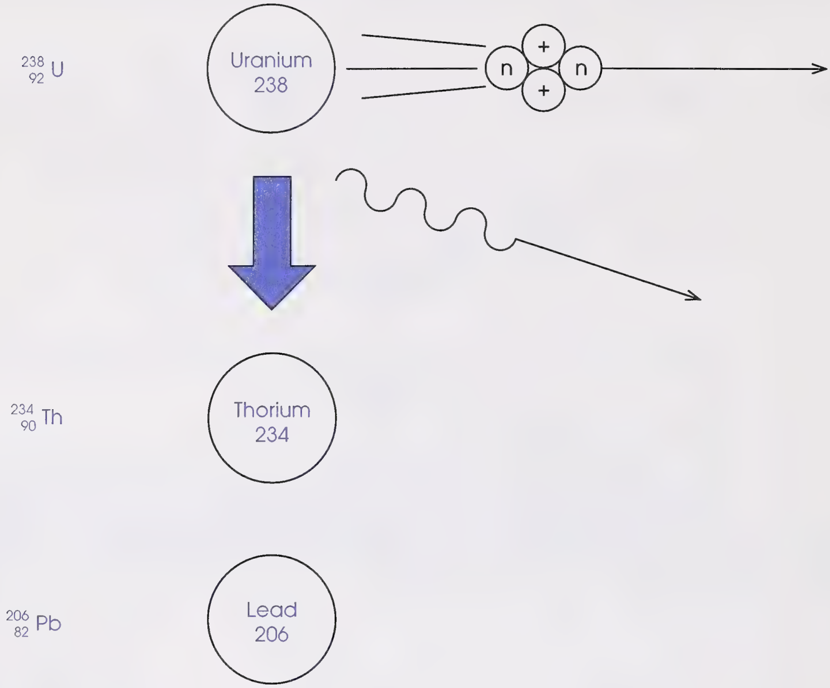
Unfortunately, nuclear reactors produce more than just huge amounts of energy from small amounts of fuel. The spent fuel is highly radioactive and creates problems of its own. The photo shows a storage bay inside a nuclear power station where radioactive used fuel is safely stored. The next program will introduce you to the issues surrounding spent fuel and its storage.

CANADIAN NUCLEAR ASSOCIATION

Familiarize yourself with the following questions about the main ideas from the program called *Nuclear By-Products*. You will have to stop the tape periodically so that you can answer the questions.

18. Which is more radioactive, the original fuel or the spent fuel?

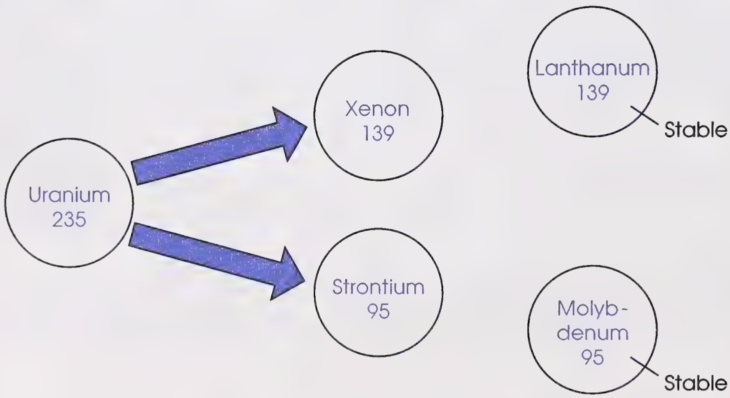
19. Copy the following diagram into your notebook. Be careful to leave enough space to record your answers.



a. Label the diagram in your notebook to show how many decay steps there are between the thorium and the lead.

b. Label the diagram in your notebook to show the types of radiation emitted.

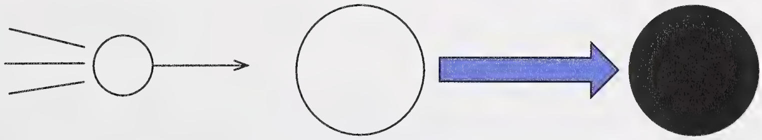
20. Copy the following diagram into your notebook. Be careful to leave enough space to record your answers.



a. Label the diagram in your notebook to show how many decay steps there are between xenon 139 and lanthanum 139.

b. Label the diagram in your notebook to show how many decay steps there are between strontium 95 and molybdenum 95.

21. Copy the following diagram into your notebook. Be careful to leave enough space to record your answers. Complete the diagram by adding labels to illustrate which reaction produces 30% of the energy in a nuclear reactor.



22. Explain why the spent fuel is still so dangerous after removing it from the reactor, even though fission has stopped.

When the program ends, stop the tape.

Check your answers by turning to the Appendix, Section 1: Activity 4.

Learning about the basics of generating electricity from nuclear energy may help you understand the physics behind it, but to understand the controversy requires the study of risk. This is the topic of Section 2.

Follow-up Activities

If you had difficulties understanding the concepts in the activities, it is recommended that you do the Extra Help. If you have a clear understanding of the concepts, it is recommended that you do the Enrichment.

Extra Help

Becquerel discovered that radiation is given off spontaneously from certain substances.

The number of protons in a nucleus is given by the atomic number (Z) of the element. The number of protons plus the number of neutrons in the nucleus is given by the atomic mass (A) of the element.

1. List the atomic number, the atomic mass, the number of protons, and the number of neutrons for the following atoms.

   a. neon b. calcium c. boron

2. Draw a labelled model of carbon 14.

3. Complete the following nuclear equations. Write the complete equations in your notebook.

   a. ${}^{116}_{49}\text{In} \rightarrow {}^{116}_{50}\text{Sn} + \underline{\hspace{3cm}}$ b. ${}^{72}_{30}\text{Zn} \rightarrow {}^{0}_{-1}\text{e} + \underline{\hspace{3cm}}$

The nucleus has less energy than its individual protons and neutrons due to the strong nuclear force. This energy is called the binding energy of the nucleus. It is calculated by using Einstein's formula, $E = mc^2$.

4. A nucleus decays and releases 1.8×10^{-13} J of energy. What is the mass equivalent of this energy?

Check your answers by turning to the Appendix, Section 1: Extra Help.

Enrichment

Do **one** of the following activities.

1. Use a library resource to research information on an ionizing smoke detector. Describe how it operates.

2. One of the important uses of radioactivity is determining the age of objects. The technique of using carbon 14 as a dating material was discovered in the 1940s. Since then it has been used by archaeologists all over the world.

   A reaction takes place between cosmic rays and nitrogen in the atmosphere.

   $${}^{14}_{7}\text{N} + {}^{1}_{0}\text{n} \rightarrow {}^{14}_{6}\text{C} + {}^{1}_{1}\text{H}$$

   This carbon 14 is radioactive and decays to produce ${}^{14}_{7}\text{N}$ and ${}^{0}_{-1}\text{e}$ with a half-life of 5730 y. However, the carbon 14 is present in the atmosphere and is absorbed by plants through CO_2 in the process of photosynthesis. The concentration of ${}^{14}_{6}\text{C}$ in the material of an object can indicate the object's age.

The age of the object can be determined using the following equation.

$$t = \left(1.90 \times 10^{4}\ \text{y}\right) \log \frac{15.3/\text{min} \bullet \text{g}}{\text{rate}}, \text{ where rate} = \frac{\text{disintegration rate}}{\text{mass of carbon}}$$

Two samples of fossils are brought in for you to analyse. One sample is believed to be over 3000 y old. Its rate of disintegration is 8.25 per minute per gram of carbon.

a. Calculate the fossil's age. Is the fossil over 3000 y old?

b. Another sample is found to have a disintegration rate of 4.5 per minute per gram of carbon. How old is it?

Check your answers by turning to the Appendix, Section 1: Enrichment.

Conclusion

In this section you have learned how the discovery of radioactivity led to the idea that energy could be obtained from radioactive materials. You've seen from calculations that it does not take very much mass to liberate huge amounts of energy. Nuclear reactions have been put to many uses that range from treating cancer to generating electricity.

In the next section you will learn how people assess the risks associated with these technologies.

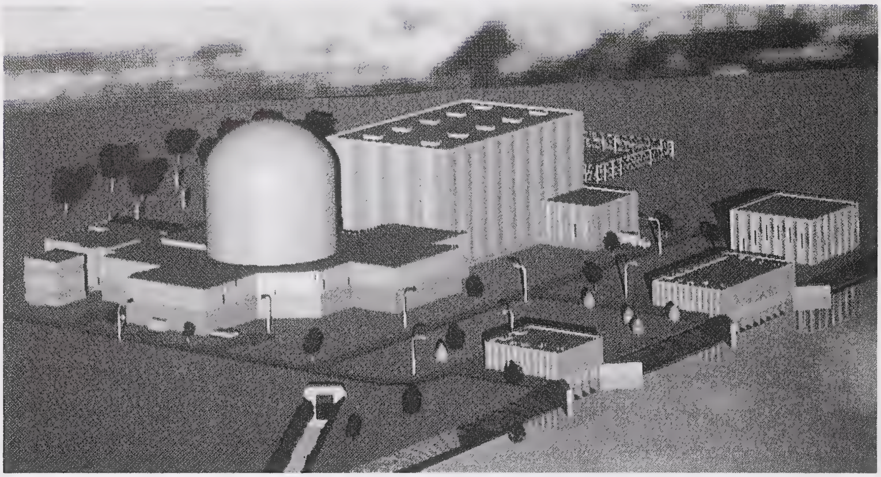
Assignment Booklet

ASSIGNMENT

Turn to your Assignment Booklet and do the assignment for Section 1.

Section

2 Living with Risks



CANADIAN NUCLEAR ASSOCIATION

The computerized illustration shows a CANDU 3 nuclear generating station. If a nuclear power plant was going to be built within 10 km of where you live, how would you respond? Now that you have completed Section 1 of this module, you are knowledgeable about the physics of nuclear energy. Your friends, neighbours, and family probably don't know as much as you do about nuclear physics. How would they respond to the announcement of a nuclear power plant being built nearby?

The range of reactions in your community would likely be typical of other communities that have actually lived through this experience. This is an issue that tends to produce very different opinions. Some experts say that it is quite safe, while citizens claim that the risks are too high. Why does this topic tend to produce such extreme opinions about the risk involved?

In this section you will learn what risk means. You will then survey the methods used by experts to assess risks, as well as the factors considered by members of the general public when they determine risk. Finally, you will apply your knowledge of nuclear energy and risk/benefit analysis to make an informed decision about the future of nuclear generating stations.

Activity 1: Risk Assessment by Experts

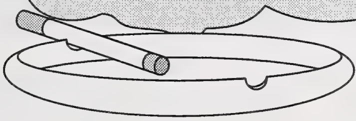
If the proposal was made to build a nuclear power plant within 10 km of your home, expert advice would most certainly be sought.

Experts in the field of risk assessment examine the risks involved with a hazard for the following reasons:

- Risk assessment helps find ways to avoid, reduce, or otherwise manage risks.
- Risk assessment helps illuminate all the aspects of a situation so it can be better understood.
- Risk assessment can be used as a design tool for new technologies. Since the technology is new, no one knows how the whole process will work and how it is likely to break down. Risk assessment can be used to imagine all possible accidents and then design an independent safety device that can be added to each component. This is how nuclear power plants are designed. A total system failure in a nuclear power plant requires many components and their matched safety devices to fail one after the other. Since this is a remote possibility, many experts maintain that major accidents at nuclear power plants are very unlikely.

You can see from the kinds of things done by those in the field of risk assessment that uncertainty is at the heart of this work. The handling of data to predict uncertainties requires the mathematical techniques of probability and statistics. Statistics is the language of risk assessment. As an example, consider the following statistics that assess the risks from smoking cigarettes:

- Every cigarette that you smoke takes 5 min off your life.
- Thirty percent of all cancers are attributable to cigarette smoking.
- Every cigarette that you smoke increases your chance of death by a factor of 1 in1.4 million.
- Smoking one pack of cigarettes a day for 1 y has an associated mortality rate of 3600 deaths in 1 million people.
- People who smoke a pack a day for 50 y will, on average, shorten their life span by 3.5 y.



1. Show that the first and last statistics are consistent with each other by doing a calculation. Note that there are twenty-five cigarettes in one pack.

2. Show that the third and fourth statistics are close, but not perfectly consistent with each other, by doing a calculation.

3. If you sat down and quoted these statistics to a person who smoked one pack of cigarettes a day, what would the response likely be? Would more statistics help?

Although many experts feel that risk assessments should be expressed in as many different ways as possible to help deepen the understanding of the problem, the truth of the matter is that the average person may not be able to understand what the statistic really means, especially if the probability is very low.

Some psychologists have suggested that the reason for this is that most people can only understand a range of numbers that are separated by a factor of 10^4. In other words, telling a person that the probability of an event happening is 1 in 10 000 is about the limit of true understanding. Beyond that, the meaning is lost.

4. Explain why the statistic that each cigarette increases your chances of death by a factor of 1 in 1.4 million is a meaningless statistic to many people.

Check your answers by turning to the Appendix, Section 2: Activity 1.

You can see that the statistical estimates of risk that are produced by experts in the field of risk assessment can become "just another statistic" to the general public.

The general public uses a different set of strategies to determine risk. Because these strategies are not based on detailed statistical analysis, the result is referred to as a risk perception rather than a risk assessment. Different strategies produce different outcomes in terms of determining risks. You'll learn more about this in the next activity.

Activity 2: Risk Perceptions by the General Public

A perception is an opinion formed in the mind of an observer. When a citizen is asked to determine risk, the result is a risk perception that is based on a judgement of the hazard.

What criteria do people use in forming a perception of risk? Psychologists have conducted a number of studies to answer this question. Although the detailed answers that people give will vary from hazard to hazard and from one observer to the next, there are trends in the criteria used to form a perception of risk.

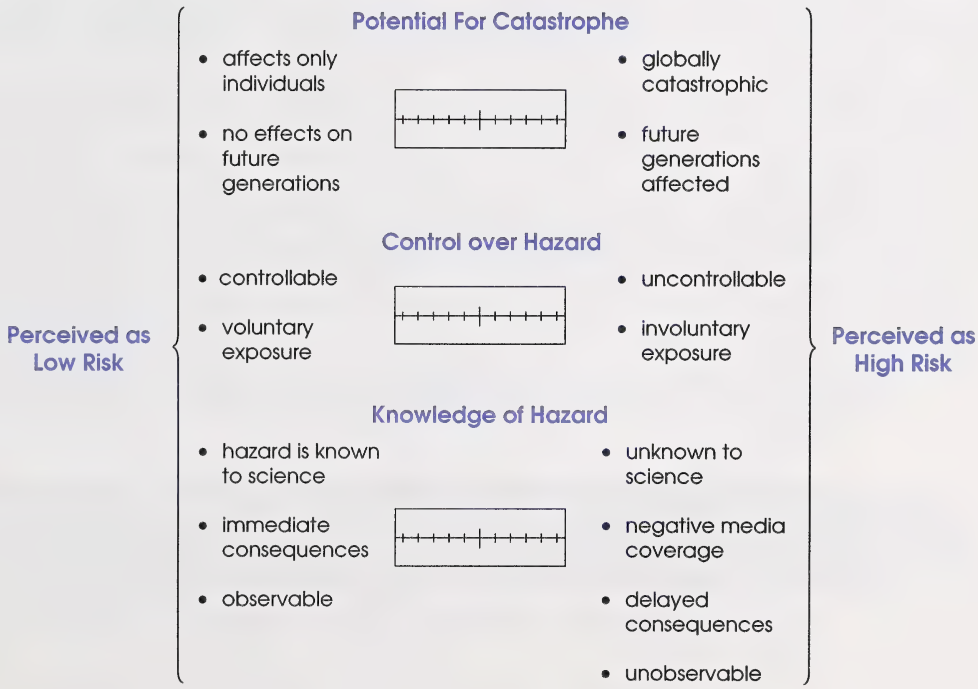
Factors Most Often Used to Form a Risk Perception

Potential for Catastrophe: If the potential exists for killing a large number of people in a very short time, or if the possibility exists for harming future generations, the hazard is perceived to be a high risk.

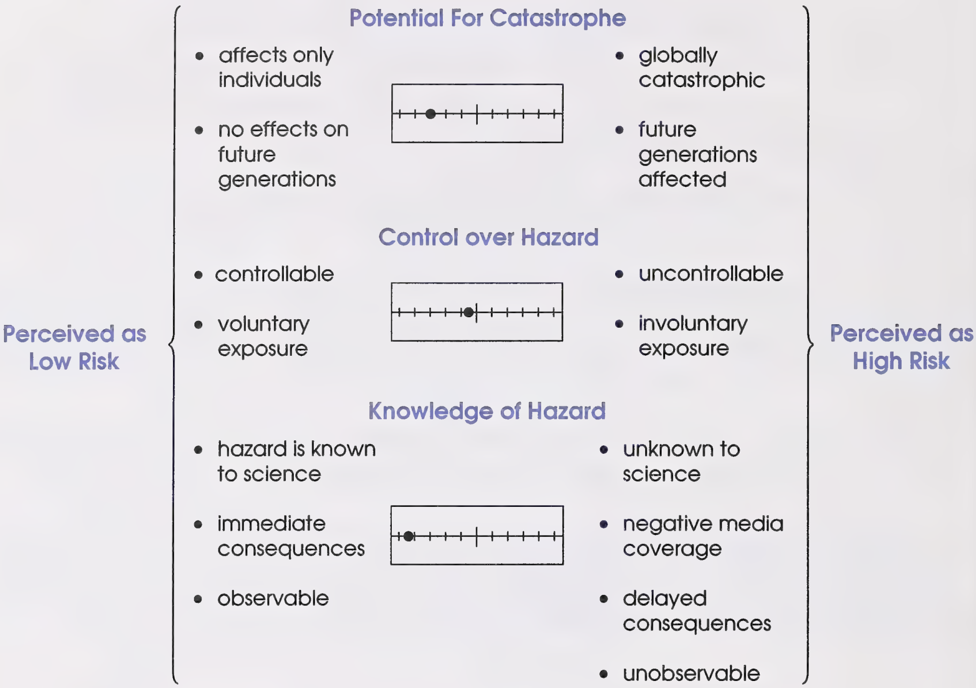
Degree of Control: If the individual feels that they have little control over the hazard, the hazard is perceived to be a high risk.

Knowledge: If the only knowledge that an individual has of a hazard comes from the media (which tends to focus on threats to health and mishaps), or if the individual feels that the hazard is new, undetectable, and unknown to science, the hazard is perceived to be a high risk.

One way to communicate a risk perception using these factors is to put each factor on a continuum, with the extreme points of view at each end.



By referring to these factors, it is possible to speculate why the general public judges some things to be of greater risk than others. For example, consider the perception of risk that most people have towards motor vehicles. The following continuum represents why most people regard motor vehicles as a relatively safe form of travel.



Since most motor vehicle accidents involve individuals, and have no effect on future generations, the potential for catastrophe is low. The matter of control over the hazard may at first seem high because you choose to be in the vehicle and you may even be driving. However, the actions of other drivers add a level of uncontrollability. Virtually everyone has had first-hand experiences with cars. Media coverage is mixed, with positive coverage (car commercials on TV) and negative coverage (accident reports on the news). In this case, the knowledge of the hazard tends to favour a low perception of risk.

You can see why motor vehicles might be judged as having a low to moderate risk. However, this perception would not match the numerical risk assessment by the experts who have determined motor vehicles to be among the top three causes of death in Canada. Depending on how the study is done, details will vary, but it is recognized that motor vehicles, cigarette smoking, and the consumption of alcohol are leading causes of death in Canada.

Science Skills

- ❒ A. Initiating
- ❒ B. Collecting
- ❒ C. Organizing
- ❒ D. Analysing
- ❒ E. Synthesizing
- ☑ F. Evaluating

1. Using the previous example as a guide, use the continuums to determine how you think most people would rate non-nuclear electric generating stations as a hazard. Support your answer by explaining each rating. What overall risk would be perceived by the general public?

As with the last case, the experts' numerical risk assessment does not agree with the public perception of risk. Whereas the conventional nature of generating electricity (using known technology) may give people the perception that it is relatively safe, in fact it would rank behind only motor vehicles, cigarette smoking, alcohol consumption, and handguns as the fifth largest cause of death in Canada.

Science Skills

- ❒ A. Initiating
- ❒ B. Collecting
- ❒ C. Organizing
- ❒ D. Analysing
- ❒ E. Synthesizing
- ☑ F. Evaluating

2. Use the previous continuums as guides to determine how you think most people would rate nuclear power plants. Support your answer by explaining each rating. Conclude by speculating on the overall risk perceived by the general public.

Nuclear power is the ultimate example to illustrate the difference in opinion between experts and the general public. From the public's point of view, nuclear power plants have been portrayed as being linked to nuclear weapons and global catastrophe. Mental images of large numbers of people dying and future generations being adversely affected easily come to mind. In addition, fear is generated because people have the perception that an accident would be uncontrollable, causing thousands of people to be exposed. Finally, radiation is perceived as being unobservable and having many consequences that are still unknown to science. The end result is that many people would judge nuclear power to be one of the top hazards to the citizens of Canada.

In sharp contrast, the experts would say that the probability of death from living a lifetime next to a nuclear power plant is the same as driving 120 km in an automobile. Think about what this statistic is saying: it is safer to live a lifetime beside a nuclear power plant than it is to drive from Calgary to Red Deer (145 km)! Statistically, the probabilities are so low that the experts would not even rate nuclear power within the top twenty causes of death in Canada. Yet in the minds of some people, the overwhelming dread of a large-scale nuclear accident renders all statistics meaningless, no matter how low the calculated probability is.

This situation goes beyond who's right and who's wrong. In the next activity you will see that the wide gulf between these points of view has several adverse effects on society.

Check your answers by turning to the Appendix, Section 2: Activity 2.

Activity 3: Risk Assessments Versus Risk Perceptions

Many people think that nuclear power is just the first of a series of new technologies that will cause the general public and experts to be at odds when it comes to determining risks. It's been said that one of the only things you can count on is change. The future will bring many new technologies. It is important for both the experts and the general public to reach common ground when it comes to the management of risk. If both groups maintain the kind of sharp divided opinions that surround the nuclear power issue, there will be several negative consequences for society:

- Citizens will live in a perpetual state of fear about the perceived risks from the hazards in their lives. Although people may live in what many consider to be the richest and most resourceful civilization, the high level of anxiety may seriously detract from the quality of life.

- Economically, the costs to the national economy due to disagreements about risk are enormous. Money spent on lengthy court battles, costly delays, misplaced investments, and retrofits reflect the inability of industry to predict what level of risk will be accepted by the general public.

- Law makers can become paralysed in making public policy because of the radically different expectations of individual special interest groups. Imagine that you are an elected official working to draft new laws related to public safety. On one hand you must answer to citizen groups, who may demand zero risk, which in itself is an impossibility, while on the other hand you need to consider the needs of industry to produce a product or provide a service at a competitive price. Both groups claim that the issue is one of survival and there is no room for compromise. How do you satisfy all of these competing viewpoints? Unfortunately, the safest political move is often to make no decision or to refer the problem to a committee and try to offend as few people as possible to ensure re-election. The whole process of drafting the public safety legislation becomes paralysed.

1. How can the previous situation be resolved? List some concrete suggestions that would help.

Perhaps the most important thing is for both sides in the debate to respect the intelligence and the insights of the other side. Experts must not be so arrogant and must not refer to the concerns of the general public as imaginary risks. The general public has a broad concept of risk that includes legitimate concerns that are often left out when experts do their risk assessments. The general public must accept the responsibility of being the decision makers. The public needs to become better informed and also needs to take an active role in finding workable solutions.

Making an Informed Decision

Your role as a decision maker begins right now. You are now a citizen who is informed and educated about the physics of nuclear power and the nature of risk. You are now ready to play an important role as an informed citizen. In the remainder of this activity you will apply all of your skills.

You will be given the opportunity to choose one of two topics and you will attempt to make an informed decision on the issue. There are no right or wrong answers, but you must adopt a concrete position. The focus is not on your choice, but on how well you support your choice with clear reasoning that is supported by examples. To help you with this process, you will be asked questions that will help you identify important pieces of information and organize your thoughts.

Science Skills

- ☐ A. Initiating
- ☑ B. Collecting
- ☑ C. Organizing
- ☑ D. Analysing
- ☑ E. Synthesizing
- ☑ F. Evaluating

PATHWAYS

If you have access to the video *Nova: Back to Chernobyl*, do Part A.
If you do not have access to the video tape, do Part B.

Part A

At the end of this activity you will be asked which of the following opinions you support. You must choose one of these opinions.

Opinion A	Opinion B
The accident that occured in April 1986 at the nuclear reactor at Chernobyl signals the end of the peaceful use of nuclear energy in our time.	The accident that occured in April 1986 at the nuclear reactor at Chernobyl allowed valuable lessons to be learned. These lessons will take the peaceful use of nuclear energy into the next century.

The video tape is nearly one hour long, so you will need to stop the tape periodically to answer the questions. It is recommended that you familiarize yourself with the questions before you begin.

2. Two months before the accident, the citizens of Pripyat were told the odds of a meltdown occuring. What estimate was given?

3. In reviewing the clean-up procedures, some people now say that the clean-up happened much too quickly. What is the concern about the speed of the clean-up?

4. The video makes it clear that there are important differences between the Soviet RBMK reactor and reactors used in North America. For both the Soviet reactor and

the North American reactors, list the grade of uranium that is used, the moderator, and the consequences if the water is boiled away. Also indicate if there is a containment building and if operator error could contribute to an accident.

5. The video makes the point that the accident at Chernobyl was due to bad design and irresponsible operation. What two rules did the operators violate?

6. When a government is committed to nuclear power, the wrong impression that nuclear power is absolutely safe can be given. Why is it a dangerous premise for operators?

7. Why weren't safety drills routinely done at the plant?

8. Quickly trace the following map into your notebook. To save time you may wish to focus only on the coastline and the places that are labelled. Answer the following questions by labelling the map as directed in each part.

a. Draw the area to which the winds carried the radioactive cloud on the first two days. Label this area by writing **Day 1** and **Day 2**.

b. Draw the areas influenced by the cloud by day 5. Label this area by writing **Day 5**.

c. Draw the area occupied by the radioactive cloud after the fifth day. Label this area **After Day 5**.

d. On the first day it rained in Sweden. Label this area **Rain**.

e. On the second day it rained in southern Germany (by the border with Switzerland). Label this area **Rain**.

9. In the previous question you identified two areas where it rained. What is the significance of the rain? Give examples from each location.

10. Experts disagree about the number of cases of cancer that will result from the Chernobyl accident.

    a. List the three estimates provided on the video tape.

    b. Based on your knowledge of risk assessment, why don't the experts all estimate the same number of cases?

11. How do low levels of radiation affect a person's chance of getting cancer? Explain why this question is so difficult to answer.

12. Return to the two opinions expressed at the beginning of Part A. Choose one of these opinions and support it by addressing each of the following specific items.

    - What is your general perception of the risks for nuclear power?
    - Explain what your perception of risk is based on. Be specific.
    - Explain how the information presented in the video tape supports your perceptions of the risks involved. Give examples.
    - Conclude by explaining which opinion you prefer. Support your answer.

End of Part A

Part B

At the end of this activity you will be asked which of the following opinions you support. You must choose one of these opinions.

Opinion A	Opinion B
A nuclear generating station should not be considered as a way to generate electricity in Alberta in the next twenty years.	A nuclear generating station should be considered as a way to generate electricity in Alberta in the next twenty years.

You will be referring to newspaper articles and information sheets published by the Canadian Nuclear Association. These resources can be found at the end of the Appendix. Before you read each resource, familiarize yourself with the appropriate questions that apply to that resource.

Read the article "Reactor Proposal Draws Ire" in the Appendix and then answer questions 13 and 14.

13. Describe the point of view of the director of the Environment Centre of Alberta.

14. Describe the point of view of the spokesman for Saskatchewan Power.

Read the article "Nuclear reactor option defended" in the Appendix and then answer questions 15 and 16.

15. Why does the University of Calgary physics professor consider a nuclear reactor an environmental advancement for Saskatchewan? Explain fully.

16. What are the arguments for and against converting Alberta's coal-fired electric power plants to natural gas?

Read the article "Alberta wary of Sask. nuclear project" in the Appendix and then answer questions 17 and 18.

17. According to the Alberta Environment Minister, what are the recommended methods for generating electric power on the three prairie provinces?

18. Compare the comments of the Alberta Environment Minister to the environmental concerns of the University of Calgary physics professor in the previous article.

Coal-fired plants produce about 85% of Alberta's electricity because coal is inexpensive and accessible. Alberta has about 60% of Canada's proven coal reserves.

ALBERTA PUBLIC AFFAIRS BUREAU

Read the fact sheet called "What are the Main Advantages of Nuclear Energy" in the Appendix. Then answer questions 19 and 20.

19. According to the information provided, what are the overall advantages of generating electricity from nuclear power?

20. Why is nuclear energy a better option for the environment?

Read the article "Use of nuclear reactors to extract heavy oil studied" in the Appendix. Then answer question 21.

21. What role could a nuclear reactor play in helping to extract heavy oil from tar sands?

Read the editorial "A nuclear Alberta?" in the Appendix. Then answer the following questions.

22. Earlier you read an article that described the possibility of a nuclear power plant in Saskatchewan. What reason does the editor give for the arrangement between AECL and the Saskatchewan government falling through?

The author of the editorial mentions the nuclear accidents at Three Mile Island and Chernobyl and a leak in a plant near St. Petersburg. The possibility of nuclear meltdown and the release of nuclear wastes into the environment was also mentioned by the director of the Environment Centre for Alberta and the Transportation and Utilities Minister.

23. In the article "Nuclear reactor option defended", a physics professor from the University of Calgary discusses the possibility of a Chernobyl-type accident in a Candu reactor. What is the professor's appraisal of this probability?

24. Return to the two opinions expressed at the beginning of Part B. Choose one of these opinions and support it by addressing each of the following specific items in your answer.

    - What is your personal perception of the risks for nuclear power?
    - Explain what your perception of risk is based on. Be specific.
    - Explain how the information presented in these articles supports your perceptions of the risks involved. Be specific.
    - Conclude by explaining which opinion you prefer. Support your answer.

End of Part B

Check your answers by turning to the Appendix, Section 2: Activity 3.

Follow-up Activities

If you had difficulties understanding the concepts in the activities, it is recommended that you do the Extra Help. If you have a clear understanding of the concepts, it is recommended that you do the Enrichment.

Extra Help

1. Construct a chart in your notebook using the headings outlined. You will need to adjust the size of your chart according to the length of your answers. Complete the chart to summarize the key ideas from this module.

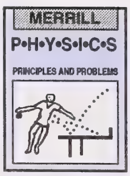
Comparing Risk Assessment to Risk Perception		
	Risk Assessment	**Risk Perception**
Who does it?		
What strategies are used?		
What is the outcome of this process?		

2. Refer to your answer to question 1 to explain why the experts and the general public sometimes have such different opinions about risk.

Check your answers by turning to the Appendix, Section 2: Extra Help.

Enrichment

Choose **one** of the following activities.



1. Radon $\left({}^{222}_{86}\text{Ra} \right)$ is the number one cause of natural background radiation in the world today. Many people are concerned about high levels of radon gas inside buildings. Carefully read page 632 of your textbook to determine what health hazards are caused by radon gas. What can be done to lower the possible risks?

MERRILL
P•H•Y•S•I•C•S
PRINCIPLES AND PROBLEMS

2. You've read about nuclear waste on page 646 of your textbook and you may have read the nuclear facts sheet called "What are the Main Advantages of Nuclear Energy?" Return to these two sources of information to help answer the following questions.

   a. Why does the average citizen perceive the risk from nuclear waste to be so high?

   b. Sometimes problems are difficult to solve because people get stuck on one track and can't imagine new possibilities. For example, some people insist that nuclear wastes are better than the air pollution and potential for global warming that fossil fuels create. Other people maintain the exact opposite position. Is there another way to look at this situation?

Check your answers by turning to the Appendix, Section 2: Enrichment.

Conclusion

In this section you've seen that there are different ways to determine the risks associated with a particular hazard. These different approaches often produce opinions that differ when it comes to determining the risks involved. As a citizen it is your role to be well informed and to take an active role in the democratic process of determining what level of risk will be acceptable to your community.

Assignment Booklet

ASSIGNMENT

Turn to your Assignment Booklet and do the assignment for Section 2.

MODULE SUMMARY

This module has introduced you to the basic ideas of nuclear physics and their applications to various technologies. You've also seen how the determination of risk is a complex issue that involves much more than just the relevant science.

Appendix

Glossary

Suggested Answers

Glossary

alpha particle – a particle that is produced by the decay of a nucleus. It has the symbol $\propto$ and is equivalent to a helium nucleus $\left({}^{4}_{2}\mathrm{He} \right)$.

atom – the smallest particle of an element that shows the properties of the element

beta particle – a high speed electron produced by the decay of a nucleus. It is given the symbol β.

binding energy – the energy required to separate a nucleus into its component parts

chain reaction – one fission reaction releases neutrons that initiate other fission reactions

decay – the emission of particles by the nucleus

electron – a subatomic particle that has a negative charge

element – a substance that consists of only one type of atom

fission – complex nuclei break apart into smaller components and release energy

fusion – nuclei join to form a larger nucleus, usually with the release of energy

gamma ray – a high energy photon produced by the decay of a nucleus. It is given the symbol γ.

half-life – time required for one half of a sample to decay and produce emissions

isotopes – atoms that have the same number of protons but different numbers of neutrons

mass defect – the difference between the mass of a nucleus and the mass of its component parts

neutron – a subatomic particle that has about the same mass as a proton but that is electrically neutral

nuclear bombardment – particles colliding with the nucleus of an atom

nucleus – composed of positively charged protons and neutral neutrons. It is found at the centre of the atom.

proton – a subatomic particle that has a positive charge equal in magnitude to the charge of an electron

radioactive – having nuclei that decay and produce emissions

risk assessment – a formal statistical evaluation of the risks associated with a hazard expressed by an expert. Risk assessments usually are expressed as a probability with an accompanying uncertainty.

risk perception – an informal judgement of the risks associated with a hazard expressed by the general public. Risk perceptions are opinions that exist in the mind of the observer.

strong nuclear force – a short range force that attracts the nucleons to hold the nucleus together

transmutation – the change from one atom to another due to radioactive decay from the nucleus

Suggested Answers

Section 1: Activity 1

1. There are no right or wrong answers to this question since you are giving an opinion. The following represents typical answers given by students prior to studying this module.

Hazard

nuclear power	1	home appliances	6
motor vehicles	2	food preservatives	4
cigarette smoking	3	skiing	7
non-nuclear power	5		

2. Once again, answers to this question will vary. Many people would answer that they think of nuclear weapons when they think of nuclear power. Others might mention accidents that have been highly publicized, such as the accident at Chernobyl in 1986.

Section 1: Activity 2

1. These emission were called cathode rays.

2. The rays discovered by Faraday could be bent by electric and magnetic fields. These properties led to the conclusion that these rays were composed of negatively charged particles.

3.

	Faraday's Rays	Roentgen's Rays
Name of Rays	cathode rays	x-rays
Could the rays be bent by electric or magnetic fields?	yes	no
Were these rays nuclear radiation?	no	no

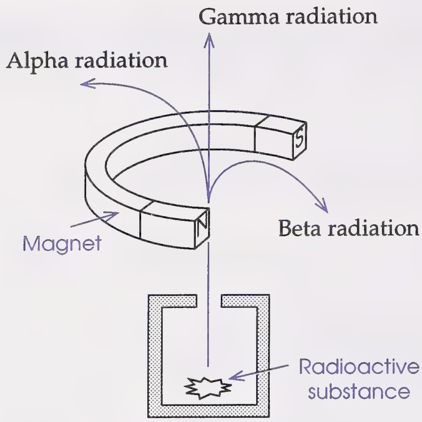
4. Becquerel wanted to know if fluorescent materials also emitted x-rays.

5. The Becquerel rays emitted by the uranium compound were given off continually, while the x-rays were only emitted if a cathode ray tube had high voltage put across it.

6. The name given by Marie Curie was radioactivity.

7. The number of Becquerel rays dropped off rapidly after the first few sheets, but then declined more slowly as more sheets were added. Rutherford concluded that at least two types of radiation were being emitted. The type that was easily absorbed by a few sheets was called alpha radiation. The type that was able to penetrate many sheets was called beta radiation.

8.



9. The beta and alpha types of radiation consist of charged particles that can be deflected by a magnetic field. The hand rules for force applied to the previous diagram indicate that the alpha particles have a positive charge while the beta particles have a negative charge. Note that the smaller radius of curvature for the beta particles implies that they could have a smaller mass.

Gamma radiation is a type of electromagnetic wave that carries no charge and is therefore not deflected by a magnetic field.

10.

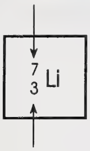
Comparing Three Types of Radiation			
	Alpha	**Beta**	**Gamma**
Type of Particle	a helium nucleus (2 protons + 2 neutrons)	an electron	a photon (a type of EM radiation)
Relative Mass	7200 times more mass than a beta particle	lighter than alpha	no mass (similar to a light photon)
Speed	slowest speed	very high speed	speed of light highest speed possible
Penetrating Ability	least penetrating ability	moderate penetrating ability	most penetrating ability
Description and Explanation of Cloud Chamber Tracks	This particle is the largest so the tracks are short and thick. Since it collides easily, it loses all of its kinetic energy in a few centimetres.	This particle is smaller than alpha particles so it can travel further between collisions. The result is a long thin track.	Gamma ray photons have no mass and the highest speed, giving few collisions. The result is a long track that is very difficult to see.

11. A transmutation is the change from one element to another.

12. The number of protons determines the identity of an atom. All the atoms of the same element have the same number of protons.

13. Atoms of the same element must have the same number of protons, but they can have different numbers of neutrons, forming isotopes.

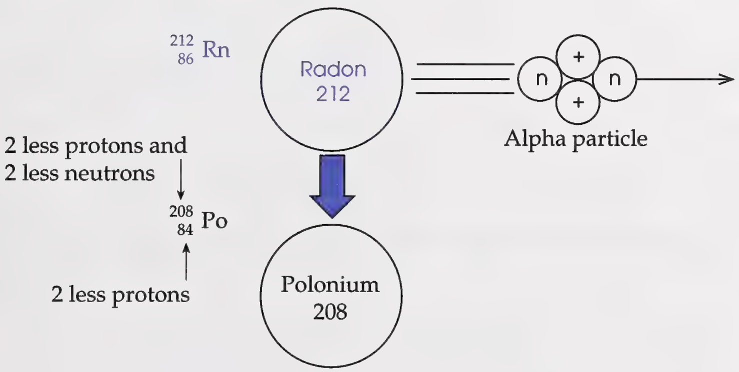
14. mass number = number of protons and neutrons in the nucleus



atomic number = number of protons in the nucleus
= number of electrons in a neutral atom

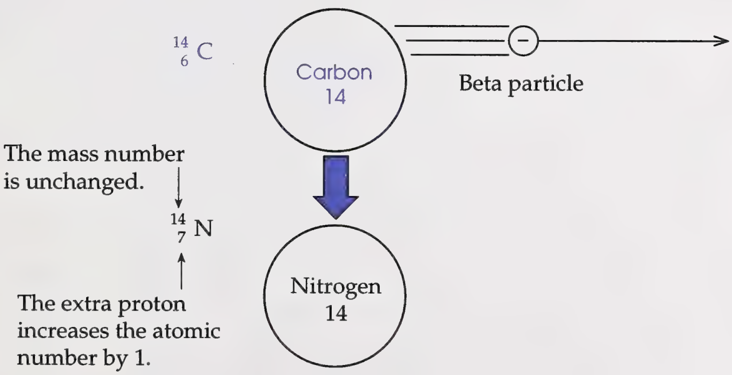
15. A chemical reaction is due to the behaviour of electrons. The nucleus is unchanged. Radioactive decay involves a change in the nucleus.

16. a.



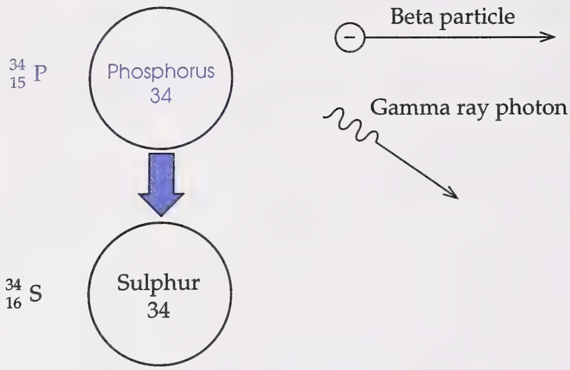
Alpha decay requires the release of two protons and two neutrons to form an alpha particle.

b.



Beta decay requires the release of an electron. This electron is not one of the outer electrons, but comes from the nucleus. To accomplish this, the nucleus does the equivalent of turning a neutron into a proton and an electron. The result is that the atomic mass stays the same but the atomic number increases by 1.

c.



Gamma decay can occur by itself, but usually it occurs with one of the other types of radiation. Since the gamma ray photon has no mass or charge, the atomic number and mass number are unchanged. In this case, the values change due to the beta emission.

17. In 24 min, half of the sample of radon 212 would have decayed to polonium 208. Twenty-four minutes is the half-life of radon 212.

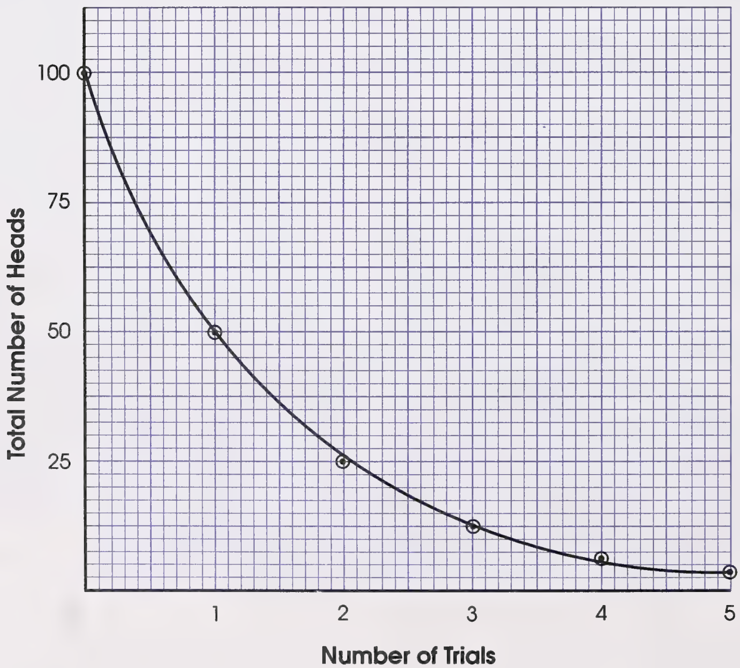
18. The half-life is the time taken for half of the atoms in a radioactive sample to decay to another isotope.

19. a. Polonium 214 has a half-life of 164 μs.
    b. Actinium 225 has a half-life of 10 d.
    c. Plutonium 236 has a half-life of 2.9 y.
    d. Uranium 238 has a half-life of 4.5 billion y.

20. The answers to this question can be found on page 686 of your textbook.

21. Textbook question 1:

    The following graph shows typical results. Although individual points may vary slightly, you should have the same shape of graph.



22. Textbook question 2:

The graphs should compare very well. The important thing to check is that on each trial very close to half of the remaining coins were removed. This illustrates the idea of half-life.

23. Textbook question 1:

Without an equation, the only method that could be used to determine what percentage of the original sample would still be active would be to chart the sample though ten half-lives.

- Assume that 100% of the sample is active at $\text{time} = 0$.
- The following chart shows how the activity would change through ten half-lives.

Percentage of the Sample that Is Active	Number of Half-Lives
100%	0
50.0%	1
25.0%	2
12.5%	3
6.25%	4
3.125%	5
1.5625%	6
0.7813%	7
0.3906%	8
0.1953%	9
0.0977%	10

The chart shows that after ten half-lives, 0.0977% of the sample is still active.

24. $N = ?$
$N_o = 100\%$
$n = 10$

$$\begin{aligned} N &= N_o\left(\frac{1}{2}\right)^n \\ &= (100\%)\left(\frac{1}{2}\right)^{10} \\ &= (100\%)(0.000\,976\,5) \\ &= 0.0977\% \end{aligned}$$

25. Answers to these questions can be found on page 686 of your textbook.

Section 1: Activity 3

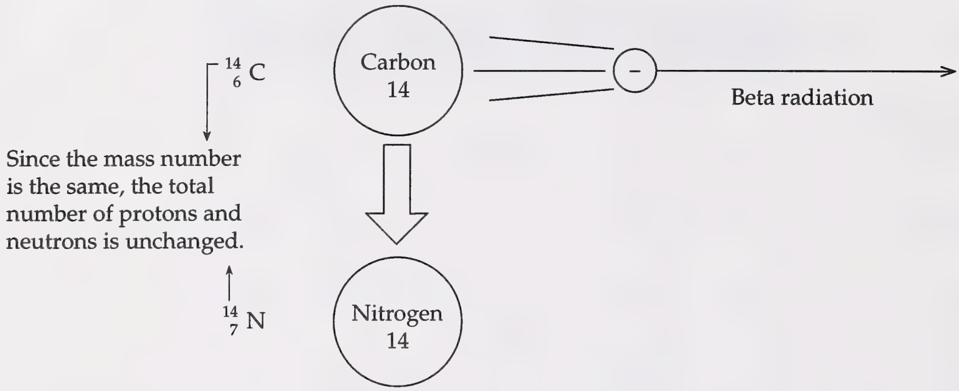
1. a. Step 1: Calculate the change in mass.

$$\begin{array}{r} \left(2.325\,28\times10^{-26}\ \text{kg}\right) \\ -\left(2.325\,26\times10^{-26}\ \text{kg}\right) \\ \hline 0.000\,02\times10^{-26}\ \text{kg} \end{array} = 2\times10^{-31}\ \text{kg}$$

Step 2: Calculate the energy equivalent.

$$\begin{aligned} E &= mc^2 \\ &= \left(2\times10^{-31}\ \text{kg}\right)\left(3.00\times10^{8}\ \text{m/s}\right)^2 \\ &= 1.8\times10^{-14}\ \text{J} \\ &= 2\times10^{-14}\ \text{J} \end{aligned}$$

b. Beta radiation is released.



The increase of 1 in the atomic number indicates an extra proton. The only way the mass number can stay the same while the atomic number increases by 1 is for a neutron to change into a proton and an electron, producing beta radiation.

This question can also be answered by using a nuclear equation.

$$^{14}_{6}\text{C} \rightarrow {}^{14}_{7}\text{N} + \boxed{}$$

The missing reaction product must have an atomic mass of zero and a charge of -1. This describes the release of an electron through beta decay.

$$^{14}_{6}\text{C} \rightarrow {}^{14}_{7}\text{N} + {}^{0}_{-1}\text{e}$$

2. $E = 2.13\times10^{-13}\ \text{J}$

$m = ?$

$c = 3.00\times10^{8}\ \text{m/s}$

$$\begin{aligned} E &= mc^2 \\ m &= \frac{E}{c^2} \\ &= \frac{2.13\times10^{-13}\ \text{J}}{\left(3.00\times10^{8}\ \text{m/s}\right)^2} \\ &= 2.37\times10^{-30}\ \text{kg} \end{aligned}$$

3. a. Step 1: Calculate the change in mass.

$$\begin{array}{r}(3.818\,32\times10^{-26}\ \text{kg})\\ -(3.817\,53\times10^{-26}\ \text{kg})\\ \hline 0.000\,79\times10^{-26}\ \text{kg}\end{array} = 7.9\times10^{-30}\ \text{kg}$$

Step 2: Calculate the energy equivalent.

$$\begin{aligned}E &= mc^2\\ &= (7.9\times10^{-30}\ \text{kg})(3.00\times10^{8}\ \text{m/s})^2\\ &= 7.1\times10^{-13}\ \text{J}\end{aligned}$$

b. Beta radiation would be released, as shown by the following nuclear equation.

$${}^{23}_{10}\text{Ne} \rightarrow {}^{23}_{11}\text{Na} + {}^{0}_{-1}\text{e}$$

The atomic number has increased by 1, indicating an extra proton. The mass number has stayed the same. As with the first question in this activity, a neutron changed into a proton and an electron, resulting in beta radiation.

4. Step 1: Calculate the total mass of the component parts.

$$\begin{aligned}\text{total mass} &= (\text{mass of one neutron}) + (\text{mass of one proton})\\ &= (1.674\,92\times10^{-27}\ \text{kg}) + (1.673\,53\times10^{-27}\ \text{kg})\\ &= 3.348\,45\times10^{-27}\ \text{kg}\end{aligned}$$

Step 2: Calculate the mass defect.

$$\begin{aligned}\text{mass defect} &= (\text{mass of component parts}) - (\text{mass of nucleus})\\ &= (3.348\,45\times10^{-27}\ \text{kg}) - (3.344\,32\times10^{-27}\ \text{kg})\\ &= 4.13\times10^{-30}\ \text{kg}\end{aligned}$$

Step 3: Calculate the energy equivalent of this mass.

$$\begin{aligned}E &= mc^2\\ &= (4.13\times10^{-30}\ \text{kg})(3.00\times10^{8}\ \text{m/s})^2\\ &= 3.72\times10^{-13}\ \text{J}\end{aligned}$$

During the fusion of deuterium, 3.72×10^{-13} J of energy would be released. This amount of energy would also be necessary to separate the nucleus into its component parts.

5. Step 1: Determine the components of a tritium nucleus.

The mass number is 3. Since tritium has one proton, it must also have two neutrons.

$$\boxed{{}^{3}_{1}\mathrm{H}}$$

The atomic number is 1, so tritium has one proton.

Step 2: Calculate the mass of the component parts.

$$\begin{aligned}\text{total mass} &= (\text{mass of one proton}) + 2(\text{mass of one neutron})\\ &= \left(1.673\,53 \times 10^{-27}\ \text{kg}\right) + 2\left(1.674\,92 \times 10^{-27}\ \text{kg}\right)\\ &= 5.023\,37 \times 10^{-27}\ \text{kg}\end{aligned}$$

Step 3: Calculate the mass defect.

$$\begin{aligned}\text{mass defect} &= (\text{mass of component parts}) - (\text{mass of nucleus})\\ &= \left(5.023\,37 \times 10^{-27}\ \text{kg}\right) - \left(5.008\,26 \times 10^{-27}\ \text{kg}\right)\\ &= 1.511 \times 10^{-29}\ \text{kg}\end{aligned}$$

Step 4: Calculate the energy equivalent.

$$\begin{aligned}E &= mc^2\\ &= \left(1.511 \times 10^{-29}\ \text{kg}\right)\left(3.00 \times 10^{8}\ \text{m/s}\right)^2\\ &= 1.36 \times 10^{-12}\ \text{J}\end{aligned}$$

This is equivalent to the binding energy for tritium.

6. Step 1: Determine the total mass of the component parts.

$$\begin{aligned}\text{total mass} &= (\text{mass of deuterium nucleus}) + (\text{mass of tritium nucleus})\\ &= \left(3.344\,32 \times 10^{-27}\ \text{kg}\right) + \left(5.008\,26 \times 10^{-27}\ \text{kg}\right)\\ &= 8.352\,58 \times 10^{-27}\ \text{kg}\end{aligned}$$

In this question, the mass of the products must also be calculated to determine the change in mass and the energy that would be released.

Step 2: Determine the total mass of the products.

$$\begin{aligned}\text{total mass} &= (\text{mass of helium nucleus}) + (\text{mass of neutron})\\ &= \left(6.646\,46\times10^{-27}\ \text{kg}\right)+\left(1.674\,92\times10^{-27}\ \text{kg}\right)\\ &= 8.321\,38\times10^{-27}\ \text{kg}\end{aligned}$$

Step 3: Determine the change in mass.

$$\left(8.352\,58\times10^{-27}\ \text{kg}\right)-\left(8.321\,38\times10^{-27}\ \text{kg}\right)=3.12\times10^{-29}\ \text{kg}$$

Step 4: Determine the energy equivalent of the change in mass.

$$\begin{aligned}E &= mc^2\\ &= \left(3.12\times10^{-29}\ \text{kg}\right)\left(3.00\times10^{8}\ \text{m/s}\right)^2\\ &= 2.81\times10^{-12}\ \text{J}\end{aligned}$$

7. No, the strong nuclear force acts the same between all the nucleons.

8. The strong nuclear force is thought to act only over a range that is equivalent to the radius of one proton, or 1.3×10^{-15} m.

9. Iron 56 $\left({}^{56}_{26}\text{Fe}\right)$ has the most negative binding energy per nucleon.

10. The atom is approximately 10^5 times larger than the nucleus. The following calculation supports this idea.

$$\frac{\text{atom}}{\text{nucleus}}=\frac{10^{-10}\ \text{m}}{10^{-15}\ \text{m}}=10^5$$

If a grape was to represent a nucleus, the corresponding diameter of a model atom would have to be 10^5 times larger.

$$\begin{aligned}\text{diameter of model atom} &= 10^5\times\text{diameter of grape}\\ &= 10^5\times10\ \text{mm}\\ &= 10^6\ \text{mm}\\ &= 10^3\ \text{m}\\ &= 1\ \text{km}\end{aligned}$$

Using a grape for the nucleus would require the diameter of the model atom to be about 1 km. That would put the outer edge of the atom about 500 m from home plate, which is beyond the bounds of the outfield fence and the bleachers in most ball parks.

Section 1: Activity 4

1. A positron is a particle that is identical to an electron except that it is positive in charge.

2. Tracer isotopes are used to help doctors follow the routes taken by molecules as they pass through the body.

3. The PET scanner can produce a three-dimensional map of internal parts of the body. It does this by carefully locating the position of isotopes that emit positrons.

4. a. It is important for the radiation to only destroy the cancerous cells. The machine rotates so that the beam of radiation will only target the cancer cells and do as little damage as possible to the healthy cells.

   b. The cobalt 60 source emits gamma radiation.

5. The irradiation of food can do the following three things to help preserve food.

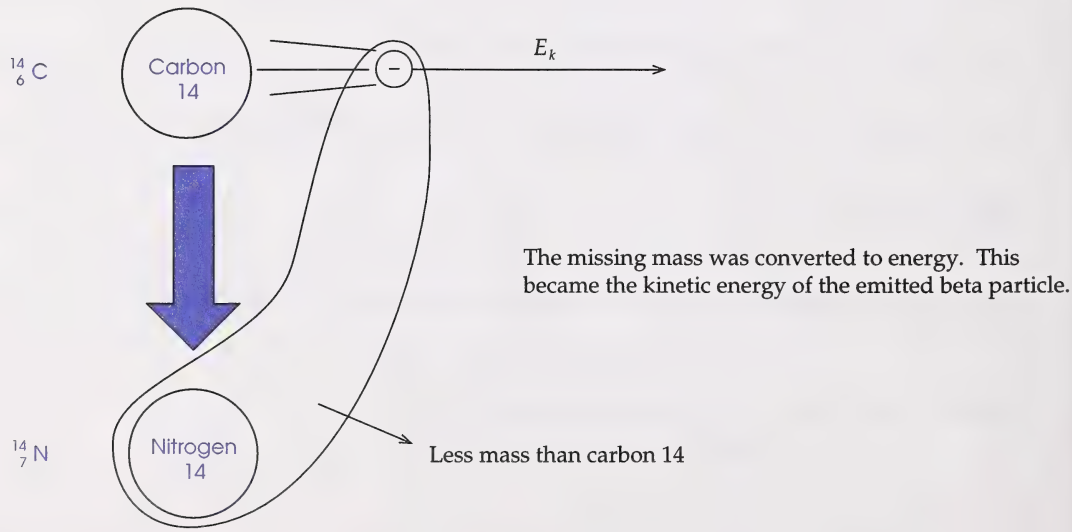
   - destroy microorganisms that cause food to spoil
   - destroy parasites and microorganisms that can cause diseases in humans
   - prolong shelf life by slowing the ripening process

6. Irradiated food is not radioactive.

7. Einstein was the first to state that $E = mc^2$.

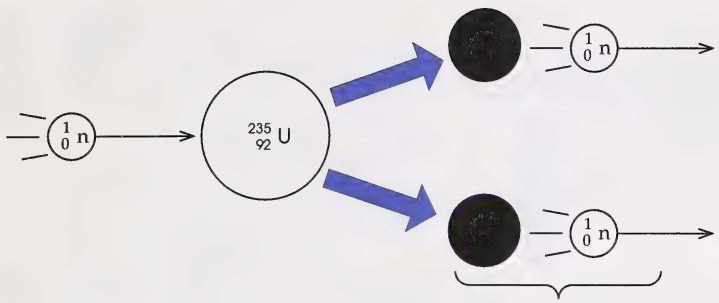
8. If this was possible, a car could be powered by one drop of gasoline for its entire useful life.

9. a.



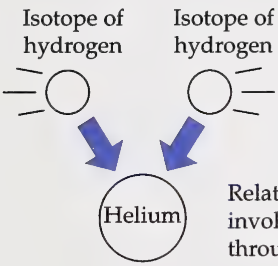
   b. This question is answered on the previous diagram.

10.



- A larger change in mass occurs here than in radioactive decay, therefore much more energy is released.
- Each neutron produced could cause another uranium atom to undergo fission, resulting in a chain reaction.

11.



Relative to the masses of the particles involved, even more energy is released through fusion (compared to fission).

12. Normally, the uranium 238 that is present in the ore absorbs the neutrons, preventing the chain reaction. In addition, uranium 235 makes up less than 1% of naturally occurring uranium.

13. The neutrons must be moving relatively slow.

14. Heavy water acts as a moderator, which means it slows down the neutrons. Ordinary water does not work as well because it also absorbs neutrons.

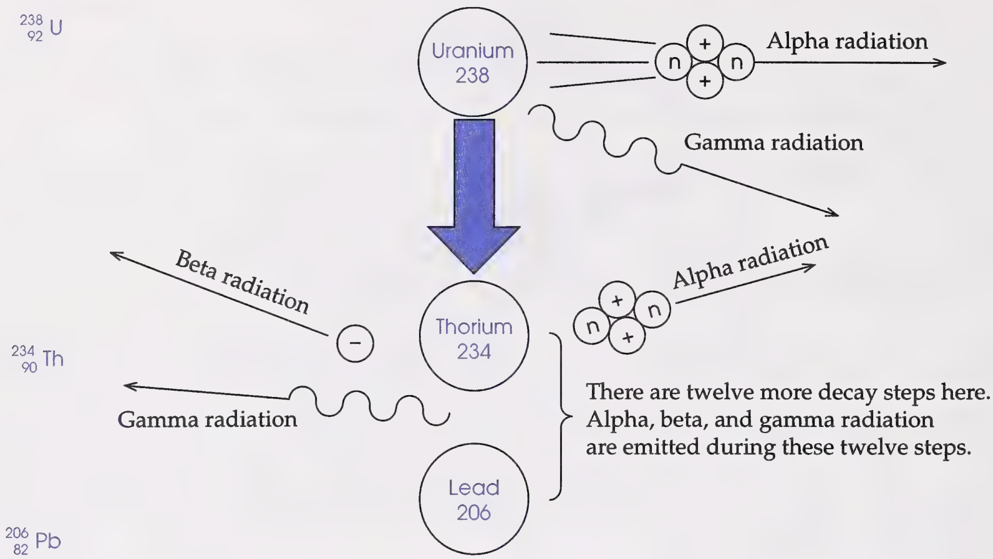
15. The control rods help to absorb enough neutrons so that the reaction does not proceed too quickly and produce too much energy. The production of too much energy might cause a meltdown.

16. The kinetic energy of the fission products causes the water to become super-heated.

17. No, the super-heated water is in contact with the radioactive fuel, so it must not be allowed to leave the containment building. This water is also pressurized so that it will not boil. The super-heated water passes its heat through a heat exchanger to water in a separate container that is then allowed to produce steam.

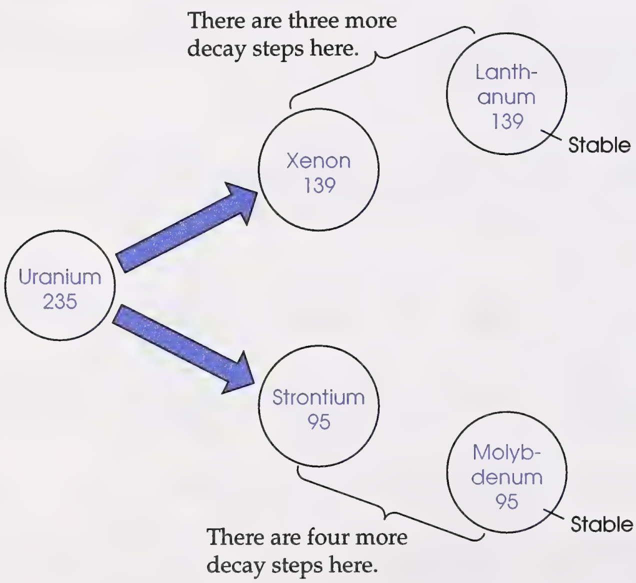
18. The spent fuel is more radioactive than the original fuel.

19. a.



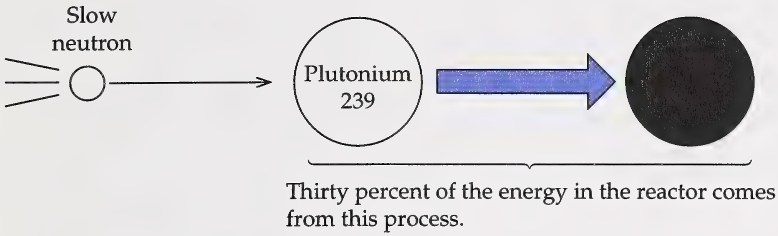
b. This question is answered on the previous diagram.

20. a.



b. This question is answered on the previous diagram.

21.



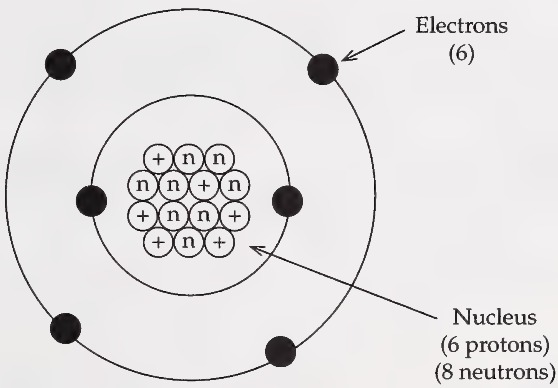
22. The spent fuel is still dangerous because it contains so many different radioactive isotopes, all in various stages of radioactive decay, continually emitting all three types of nuclear radiation.

Section 1: Follow-up Activities

Extra Help

1. a. Neon's atomic number is 10 and its atomic mass is 20. It has ten protons and ten neutrons.
   b. Calcium's atomic number is 20 and its atomic mass is 40. It has twenty protons and twenty neutrons.
   c. Boron's atomic number is 5 and its atomic mass is 11. It has five protons and six neutrons.

2. atomic number = 6 (6 protons and 6 electrons)
   atomic mass = 14 (6 protons + 8 neutrons)



This diagram is not drawn to scale. The nucleus should be 100 000 times smaller than the atom.

3. a. $^{116}_{49}\text{In} \rightarrow {}^{116}_{50}\text{Sn} + {}^{0}_{-1}\text{e}$

Atomic mass is conserved (left-hand side = 116 / right-hand side = 116).

The atomic number is conserved $\left[49 = 50 + (-1)\right]$.

This is a beta decay in which a neutron changed into a proton and an electron (beta particle).

b. $^{72}_{30}Zn \rightarrow ^{0}_{-1}e + ^{72}_{31}Ga$

Atomic mass is conserved (left-hand side = 72 / right-hand side = 72).
The atomic number is conserved $[30 = 31 + (-1)]$.
This is also an example of beta decay.

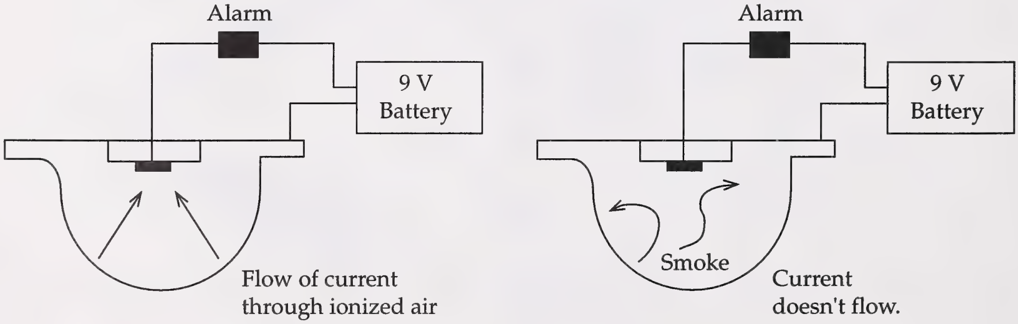
4. $E = 1.8 \times 10^{-13}\ J$
$m = ?$
$c = 3.00 \times 10^{8}\ m/s$

$$
\begin{aligned}
E &= mc^2 \\
m &= \frac{E}{c^2} \\
&= \frac{1.8 \times 10^{-13}\ J}{\left(3.00 \times 10^{8}\ m/s\right)^2} \\
&= \frac{1.8 \times 10^{-13}\ J}{9.00 \times 10^{16}\ m^2/s^2} \\
&= 2.0 \times 10^{-30}\ kg
\end{aligned}
$$

Enrichment

1. Ionizing Smoke Detector

A small amount of americium 241 (half-life = 432 y) ionizes the air in an ionization chamber in the smoke detector. The ions in the ionized air conduct a current which is registered electronically. When smoke particles enter the chamber, the current is stopped. This is registered and an alarm sounds.



2. a. $t = \left(1.90\times10^{4}\ \text{y}\right)\log\dfrac{15.3/\text{min}\bullet\text{g}}{\text{rate}}$

$= \left(1.90\times10^{4}\ \text{y}\right)\log\dfrac{15.3/\text{min}\bullet\text{g}}{8.25/\text{min}\bullet\text{g}}$

$= \left(1.90\times10^{4}\ \text{y}\right)\log\dfrac{15.3}{8.25}$

$= 5.10\times10^{3}\ \text{y}$

Yes, it is over 3000 y old.

b. $t = \left(1.90\times10^{4}\ \text{y}\right)\log\dfrac{15.3}{4.5}$

$= 1.01\times10^{4}\ \text{y old}$

$= 10\,100\ \text{y old}$

The fossil is 10 100 y old.

Section 2: Activity 1

1. Consider the last statistic that was given.

- time that life is shortened

$$3.5\ \text{y}\times\left[\frac{365.25\ \text{d}}{1\ \text{y}}\right]\times\left[\frac{24\ \text{h}}{1\ \text{d}}\right]\times\left[\frac{60\ \text{min}}{1\ \text{h}}\right]=1.84\times10^{6}\ \text{min}$$

- number of cigarettes smoked

$$50\ \text{y}\times\left[\frac{365.25\ \text{d}}{1\ \text{y}}\right]\times\left[\frac{1\ \text{pack}}{1\ \text{d}}\right]\times\left[\frac{25\ \text{cigarettes}}{1\ \text{pack}}\right]=4.57\times10^{5}\text{cigarettes}$$

- number of minutes per cigarette

$$\frac{1.84\times10^{6}\ \text{min}}{4.57\times10^{5}\ \text{cigarettes}}=\frac{4.0\ \text{min}}{\text{cigarette}}$$

2. Consider the fourth statistic that was given.

- number of cigarettes

$$\left[\frac{365.25\ \text{d}}{1\ \text{y}}\right]\times\left[\frac{1\ \text{pack}}{1\ \text{d}}\right]\times\left[\frac{25\ \text{cigarettes}}{1\ \text{pack}}\right]=9131\ \text{cigarettes}$$

- Determine the mortality rate for one cigarette.

$$\frac{9131 \text{ cigarettes}}{\frac{3600}{1\,000\,000}} = \frac{1 \text{ cigarette}}{\frac{1}{x}}$$

$$\left(9131 \cancel{\text{cigarettes}}\right)\frac{1}{x} = \left(1 \cancel{\text{cigarette}}\right)\frac{3600}{1\,000\,000}$$

$$\frac{9131}{x} = \frac{3600}{1\,000\,000}$$

$$x = \frac{(9131)(1\,000\,000)}{3600}$$

$$= 2.5 \times 10^{6}$$

The mortality for one cigarette is about 1 in 2.5 million, while the third statistic said 1 in 1.4 million.

3. The numbers would likely not mean very much because they are so small. More statistics would likely not help since the numbers are so small.

4. Since most people can only understand something as small as 1 in 10 000, a statistic of 1 in 1.4 million would likely be interpreted as being the same as zero probability.

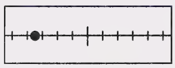
Section 2: Activity 2

1. There are no right or wrong answers to this question. A typical answer is shown. Be sure to check that your explanation is consistent with your rating on the continuum.

Perceived as Low Risk — Perceived as High Risk

Potential For Catastrophe

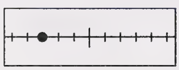
- affects only individuals
- no effects on future generations



- globally catastrophic
- future generations affected

Control over Hazard

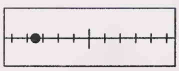
- controllable
- voluntary exposure



- uncontrollable
- involuntary exposure

Knowledge of Hazard

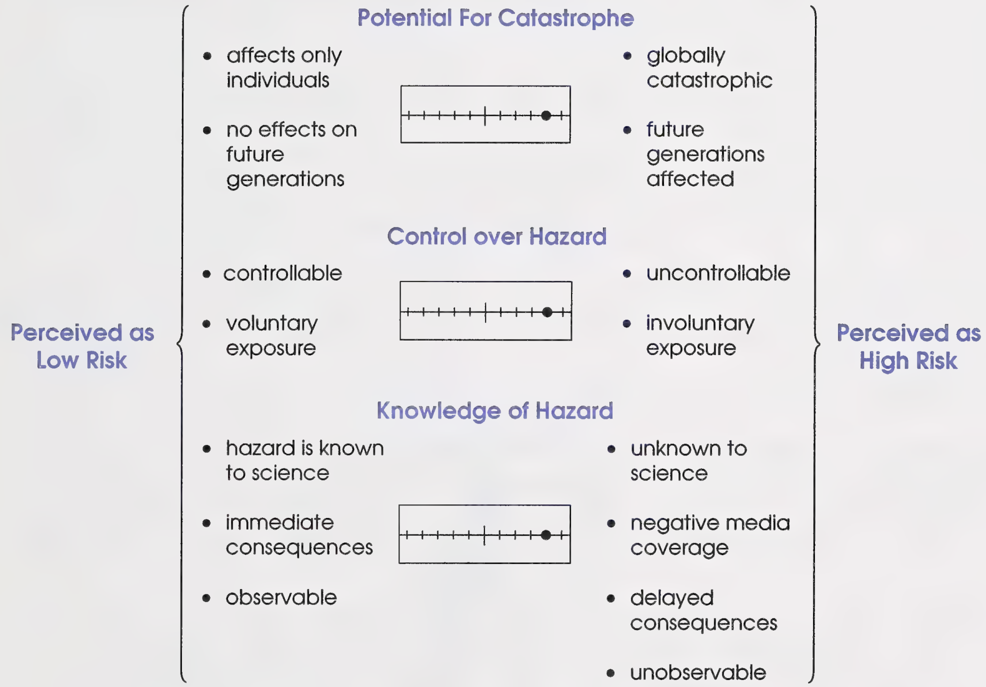
- hazard is known to science
- immediate consequences
- observable



- unknown to science
- negative media coverage
- delayed consequences
- unobservable

Using the continuum and the trends mentioned earlier, most people would probably rate the potential for a catastrophe as being low in this case. Unless you live in a valley below a hydroelectric dam, it is unlikely that you would perceive this as having the potential to kill many people. The same thinking applies to the control over the hazard. Unless you live in a valley below a hydroelectric dam, the hazard should be perceived by most people as being controllable. The non-nuclear generating stations use known, conventional technology, so the perceived risk should be low on this factor as well. Overall, most people would likely perceive non-nuclear electric power as a low risk.

2. As with the previous question, there are no right or wrong answers. A typical answer is shown. Be sure that your explanation is consistent with your rating on the continuum.



The previous response would likely reflect how most citizens would perceive the risk from nuclear power. Many people would describe a nuclear accident as being potentially catastrophic, affecting thousands of people indiscriminately with invisible, mysterious radiation and radioactive fallout. A very high perceived risk would exist in the minds of most people.

Section 2: Activity 3

1. Many possible suggestions could have been mentioned. The following list represents some of these possibilities:

   - Members of the general public may need to learn more about issues so that they can check their perceptions against the risk assessments of the experts.

- Scientific experts need to explain the nature of risk in clear, understandable language.
- The general public and experts need to communicate with each other and become more like partners looking for solutions and less like adversaries trying to prove who's right.

2. The estimate given was that a meltdown would happen once in 10 000 y.

3. The quick clean-up may have unnecessarily exposed workers to high levels of radiation.

4. Soviet RBMK Reactor: This reactor uses low-grade uranium. The moderator for this reactor is graphite blocks. If the water is boiled away, the reactor heats up more because the graphite blocks are still present. There is no containment building present. Operator error can contribute to an accident, as demonstrated by the Chernobyl accident.

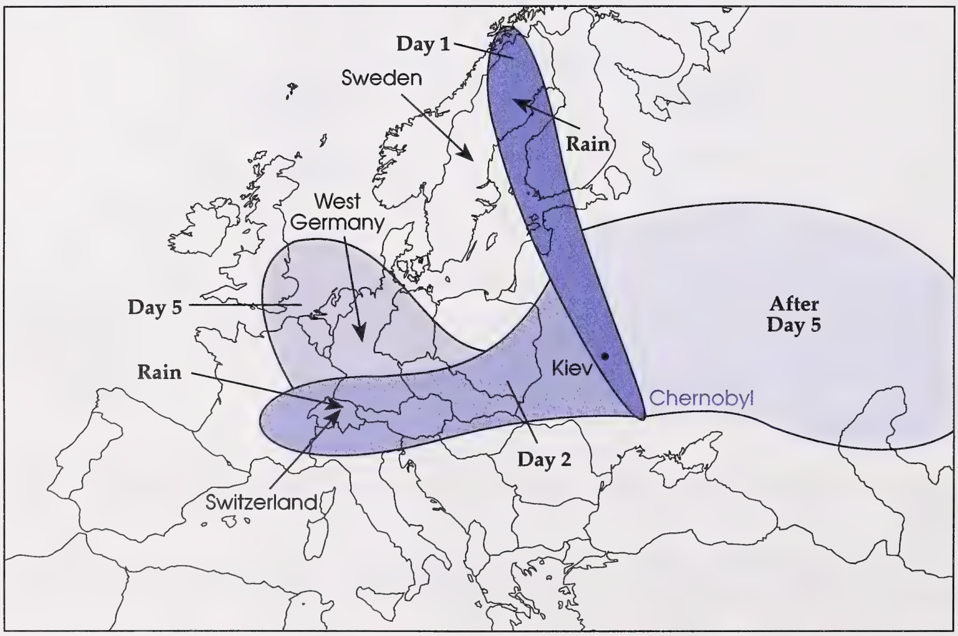
   North American Reactor: This type of reactor uses high-grade uranium. The moderator for the reactor is water. This is advantageous because the reactor will slow down by itself if it boils away its water. The reactor cannot function without water. The North American reactors do have containment buildings. Operator error can contribute to an accident, as demonstrated at Three Mile Island.

5. The operators removed all the control rods and they operated the reactor below 30% power.

6. The operators feel overconfident and take a very casual attitude toward safety.

7. Safety drills were not done because they did not want to scare the workers.

8. Parts a. through e. are answered on the map.



9. Rain brings the radioactive dust, soot, and ash down to the ground. In Sweden this meant that the radioactive materials fell on the reindeer herds and their food supply, making the animals unfit for human consumption. In Switzerland, the rain fell a few days later, meaning that the radioactive cloud could have dispersed to a greater extent, reducing the danger. However, even in Switzerland, the rain brought down small quantities of isotopes that represented the entire reactor core.

10. a. The three estimates of cancers are as follows:

    - 2000 cases of cancer outside the Soviet Union
    - 20 000 people will get cancer in the whole world.
    - Between 250 000 and 500 000 people will develop cancer.

    b. A detailed risk assessment must consider many variables. A judgement must be made about the risk and the degree of uncertainty for each variable. It is possible that different experts will make different judgements and then come to very different conclusions due to the cumulative effect of all these minor differences.

11. No one is certain how dangerous low levels of radiation really are because there is not enough data. Part of the current data comes from the survivors of the atomic bombs that were dropped on Hiroshima and Nagasaki, but this data is not complete enough to make accurate predictions.

12. The following answers represent some of the possible approaches to this question. It should be noted that it is not the particular opinion (A or B) that matters, but rather how the opinion is supported according to the criteria stated in the question.

    Opinion A

    The accident that occurred in the nuclear reactor at Chernobyl raises many questions in my mind about the safety of nuclear energy. Since I am not a nuclear phyicist, I have to consider the opinions of experts in this field before forming my own risk perception. The video has shown several instances where expert opinion was either wrong or contradictory. In this essay I will explain why these examples have caused me to perceive nuclear energy as being too risky to pursue any further.

    The first example concerns the statement made by an official two months before the accident. The citizens of Pripyat were told that the chances of a meltdown occuring were one in 10 000. Does this mean that this same reactor could now operate for 9999 y and not have another accident? Since the investigation, it has been revealed that the reactor had a bad design and was operated by poorly trained personnel, which calls into question the original statement of only one accident in 10 000 y. In my mind, this expert did not really understand what factors regarding the safety of the reactor needed to be considered. Another example is the estimate of the number of cancers world-wide that would result from the Chernobyl accident. Three experts gave estimates that ranged from 2000 to 5 000 000 cases. If these experts really understood the impact of moderate and small doses of radiation on human health, their estimates would have been closer. The video made the point that there is very little historical data relating accidents at nuclear power generators to human health. If the experts are basing their opinions on such scant information, it is not surprising that there is such a wide gulf between their estimates.

    In conclusion, the advice of experts in the field of nuclear energy appears to be less than trustworthy. It is my opinion that in light of all of this uncertainty, the best thing to do is stop the future development of nuclear energy until there is a clear concensus on issues of safety.

Opinion B

The accident that occured at the Chernobyl nuclear reactor could not happen in a CANDU type of reactor, and therefore it would be misleading to say that the accident at Chernobyl means that all nuclear reactors should be shut down. In fact, it could be argued that the accident at Chernobyl reveals that the risks associated with the responsible use of nuclear power are in fact quite low.

In the essay I will explain why this type of accident could not occur in a CANDU reactor and why I think that nuclear power is relatively safe.

The accident at Chernobyl was caused by two main things – operator error and a very poorly designed reactor. Although operator errors are impossible to extinguish from any reactor's operation, it's the bad design of the Soviet RBMK reactor that allowed the mistakes of the operators to cause the accident. The RBMK reactor used at Chernobyl had many flaws in its design, but the two most striking are the lack of a containment building and the use of graphite blocks as a moderator. The lack of a containment building means that a meltdown of the reactor core causes the release of a cloud of radioactive materials into the environment. This is what happened at Chernobyl. In Canada, all CANDU reactors are built with a containment building to prevent this from happening. The use of graphite blocks in the RBMK reactor as a moderator means that the process of fission can continue even if the water boils away. In fact, if the water does boil away, the reactor core heats up even more. CANDU reactors use heavy water as the moderator. This means that if the water boils away, the reactor will slow down by itself since it can't continue without a moderator.

Given the differences in design, it can be shown that a Chernobyl type of accident could not happen in a CANDU type of reactor. In addition, even if it could happen, the Chernobyl accident was the worst type of mishap that could possibly occur, and yet there was relatively little loss of life. Considering the annual number of deaths associated with coal mining, it would be difficult to argue that the number of deaths world-wide resulting from the use of nuclear power is more than the number of deaths resulting from generating electricity with fossil fuels. Although the accident at Chernobyl was the worst accident of its kind, it is still an acceptable risk in light of the alternative ways of generating electricity, and also considering the fact that most other reactors have a superior design.

In conclusion, Chernobyl represents the worst type of accident at a nuclear generating station and it was not really that bad. Since other reactors do not have the same design flaws, it is very unlikely that this type of accident would ever happen at a CANDU reactor in Canada.

13. The director of the Environment Centre of Alberta was very concerned about the possibility of a Chernobyl-type accident and about the potential for nuclear wastes being released into the environment.

14. The spokesman for Saskatchewan Power claimed that all sources of generating electric power have a potential impact on the environment.

15. The physics professor explains that Saskatchewan uses lignite coal in its coal-fired power plants. This type of coal is particularly bad for emitting carbon dioxide when it is burned. Carbon dioxide is a greenhouse gas which contributes to global warming. The physics professor thinks that global warming presents a much greater risk to future generations than nuclear waste does.

16. If Alberta's coal-fired plants were converted to natural gas, the amount of carbon dioxide released would be reduced because natural gas (methane) releases less carbon dioxide than coal. The Energy Minister disagrees with this move to natural gas because he claims that the pollution problem in Alberta isn't nearly as bad as in other places that switched from coal to natural gas, such as California. The Energy Minister says that Alberta's environmental standards for industry are among the strictest in North America.

17. The Alberta Environment Minister recommends that the three prairie provinces use coal and hydroelectric power.

18. The University of Calgary physics professor maintains that global warming is a greater risk than the wastes from a nuclear power plant. Burning coal contributes to the levels of atmospheric carbon dioxide and to global warming.

    The Alberta Environment Minister recommends that coal be used in addition to hydroelectric power for the three prairie provinces.

19. The overall advantages of generating electricity from nuclear power are as follows:

    - Nuclear power is inexpensive.
    - Nuclear power does not contribute to smog, acid rain, or global warming.
    - Nuclear power is safe in terms of managing wastes and being strictly regulated.
    - Nuclear energy does not depend on resources that will be depleted in the coming decades.

20. Nuclear energy is a better option for the environment because it uses less land, less total fuel, and produces less pollution and wastes.

21. A nuclear reactor could help to generate steam that is needed to extract heavy oil from tar sands.

22. The previous Saskatchewan government was replaced by an NDP government that was not in favour of generating electricity from nuclear power.

23. The professor claims that CANDU reactors are among the safest in the world, with the potential of a Chernobyl-type accident being an impossibility.

24. The following answers represent some of the possible approaches to this question. It should be noted that it is not the particular opinion (A or B) that matters, but rather how the opinion is supported in terms of the criteria stated in the question.

    Opinion A

    A nuclear generating station should not be considered as a way to generate electricity in Alberta in the next twenty years. In this essay I will outline why Alberta's current inventory of fossil fuels makes this unwise and why energy conservation should be considered first to prevent the building of any new generating stations – including nuclear ones.

    Alberta has about 60% of Canada's proven coal reserves, not to mention a healthy quantity of oil and natural gas. These energy sources are relatively inexpensive, are accessible, and they help employ Albertans. The fuel for a nuclear generating station is not available in Alberta and would not add as much to this province's economy.

    Alberta is already an energy-rich province. The best use of all our resources is to use them wisely through conservation practices. The idea of building a nuclear generating station implies that more electricity is needed, when really we should be cutting back to prevent further depletion of our natural resources and damage to the environment.

    In conclusion, the author of the editorial in *The Edmonton Journal* said it best – "Trying to interest Alberta in a nuclear industry seems a bit like trying to persuade Florida to import grapefruits."

Opinion B

Nuclear generating stations are a safe and responsible way to generate electricity. Alberta should grow out of its dependency on fossil fuels and embrace nuclear energy as a way to generate electricity. In this essay I will outline why nuclear energy is better for the environment and why it is the fuel of the future.

The conventional way to generate electricity is to use fossil fuels. When these fuels are burned, they release carbon dioxide and other substances into the environment. These substances create long-term problems.

Carbon dioxide is a greenhouse gas, which contributes to the problems of global warming. Many people, including Harvey Buckmaster, a physics professor from the University of Calgary, would argue that global warming poses more of a threat to future generations than do the problems associated with nuclear power.

Other environmental problems created by the burning of fossil fuels are acid rain and smog. Prolonged use of fossil fuels in eastern North America and Northern Europe has created major problems for fish and other organisms in delicate forest ecosystems.

Fossil fuels will not be around forever because we need the planet to stay healthy. If this is the case, Alberta should begin to reduce its economic dependency on fossil fuels to prepare for the future. Nuclear power does not contribute to smog, acid rain, or global warming and is a better option for the environment.

Section 2: Follow-up Activities

Extra Help

1.

Comparing Risk Assessment to Risk Perception		
	Risk Assessment	**Risk Perception**
Who does it?	experts	general public
What strategies are used?	Probability and statistics are used to carefully analyse available data. In many steps of the procedures, estimates have to be made, which make risk assessment an inexact science.	Studies have demonstrated that lay people tend to employ three basic criteria when determining risks: • potential for catastrophe • degree of control over the hazard • knowledge of the hazard
What is the outcome of this process?	a probability with an associated uncertainty	an opinion in the mind of the observer

2. Experts and the general public employ very different strategies, so the outcomes are often different. While the expert may focus only on things that can be measured or counted, the general public has a much broader notion of risk that encompasses considerations that may be overlooked by the expert.

Enrichment

1. Radon gas is colourless and odourless. It results from the radioactive decay of uranium. Since small amounts of uranium are found in the soil and rock everywhere on the planet, radon gas is also found. Radon gas, although present in outdoor air, is not a hazard because it is so dilute in concentration. However, in tightly sealed, energy efficient buildings, there is often little air exchange with outside air and the level of radon gas can increase in concentration.

   Radon itself is harmless, but its radioactive decay products are a cause for concern. When these decay products are inhaled, they settle on the tissues of the airways and then release alpha particles. There is some concern that this may initiate or promote lung cancer in humans.

   Although many studies have been done, there is no clear correlation between levels of radon gas and lung cancer. However some concerned homeowners have taken steps to make sure that radon gas from the ground around the foundation cannot enter the building and that the air within the building is routinely exchanged with the outside air.

2. a. As explained in the module, nuclear waste is linked to the potential for great catastrophe which can have disastrous effects on future generations. If nuclear wastes were to leak into the environment, the results could affect thousands of people indiscriminately, with invisible and virtually undetectable influences.

   b. Answers to this question will vary greatly because the idea is to creatively look at the situation in a new way. One approach would be to adopt the position that all methods of generating electricity make some form of waste that is potentially hazardous and the best thing to do is to use less electricity. Although this won't solve existing problems, at least it will keep them from getting worse. One illustration of this point is the idea that one large generating station could be closed in North America if everyone stopped using the instant-on feature on their colour television sets. The instant-on feature requires electricity to be continually running through the set so that the viewer doesn't have to wait for it to warm up.

NUCLEAR FACTS

Seeking To Generate A Better Understanding

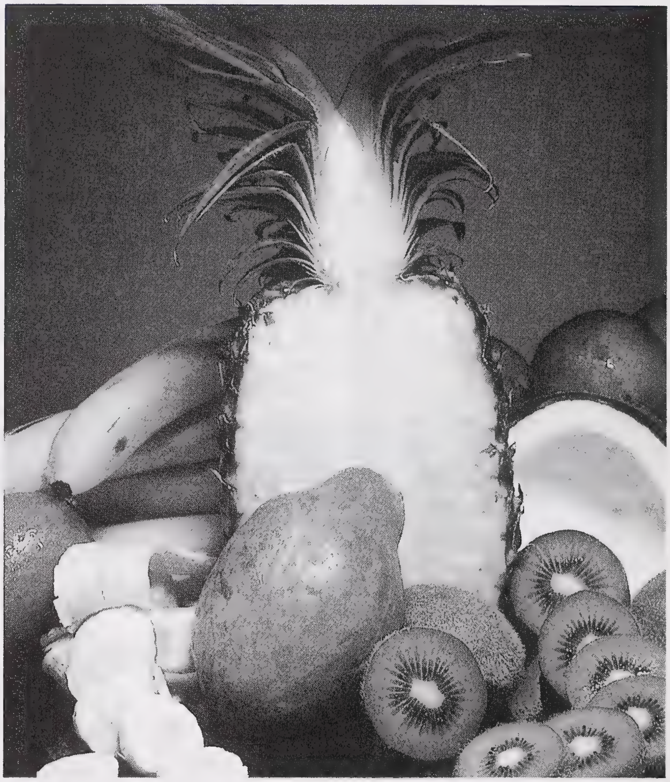
Why Food Irradiation?

The food we eat can be subjected to bacterial infection or infestations that cause food to spoil, make us sick, and even cause death. Because of this, food industry and government scientists are continually searching for effective methods of preserving food while keeping it wholesome for us to eat.

The vital need to preserve food has resulted in a variety of preservation techniques. Several of these techniques are centuries old (freezing and pickling date back more than 175 years). Canning is a more recent method, while others, such as drying and salting, are more than a thousand years old.

New and different methods replace or complement some of these conventional techniques. Food irradiation is one of them. It is a cold, non-chemical process for preserving food. Food irradiation processing equipment now makes it possible to treat some packaged or bulk foods with no significant change in taste or nutritional value.

Canada is credited with nearly 30 years of scientific research in the field of food irradiation.



Food irradiation has been researched for more than 40 years. Today, NASA astronauts eat irradiated food to help insure that what they eat remains wholesome throughout their journey in space.

What Can Food Irradiation Do?

Food irradiation can:

— preserve food by destroying the micro-organisms that normally cause spoilage;

— make food safe to eat by destroying parasites and micro-organisms that cause trichinosis and salmonella poisoning; and,

— prolong the shelf-life of foods by slowing the ripening process and inhibiting the sprouting of root vegetables like potatoes and onions.

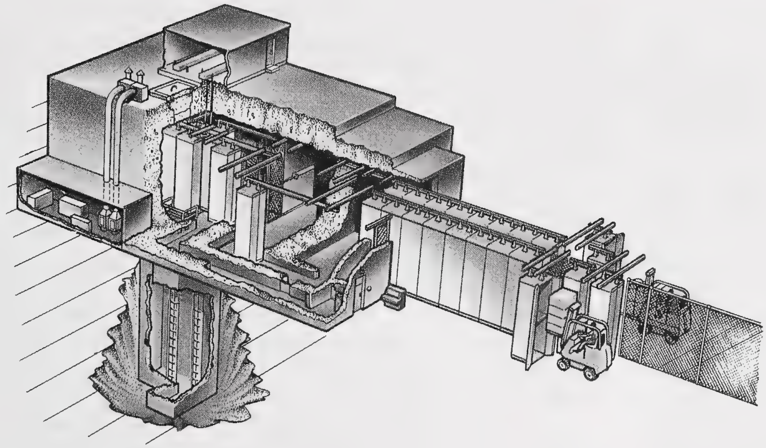
Many studies have been conducted since the late 1940's to evaluate the nutritional value of irradiated foods and to determine the safety of the process. Depending on the dosage and type of treatment, the effects on the nutritional value of food can be negligible, in which case the process can provide major benefits.

How Is Food Irradiated?

Food is irradiated similarly to the way luggage is x-rayed at airports. The food is passed through a thick-walled chamber containing a source of radiation. The ionizing radiation from gamma rays passes through the food, destroying insects, bacteria and micro-organisms.

The radiation can come from Cobalt 60, which is a radioactive isotope produced in CANDU reactors in Ontario and Quebec. Cobalt 60 is a deliberately man-made isotope with a wide range of medical and industrial uses.

(See Over)



In a food irradiator, a conveyor system automatically moves the food products through the room for irradiation.

France and England were the first to practice gamma irradiation processing on an industrial scale. Today, there are more than 140 gamma irradiators worldwide, of which 80 were supplied by Atomic Energy of Canada Limited. Ten more are now being manufactured in Canada.

Is Irradiated Food Radioactive?

No! Just as a dental x-ray does not make you radioactive, neither is irradiated food radioactive. The World Health Organization, the United Nations Food and Agricultural Organization, and the International Atomic Energy Agency have reviewed accumulated data from more than 40 years of research. They found that irradiated food is as safe as food preserved with other techniques like freezing or canning. The nutritional value of irradiated food was also found to be as good as food treated by these other processes.

The food irradiation process has been studied and tested more extensively than any other food preparation or preservation process. Decades of testing using the most recent methods in toxicology have proven that foods treated with appropriate levels of ionizing energy do not have adverse effects on the consumer.

Where Is Food Irradiation Used Now?

Today, food is irradiated in 19 countries. In the Netherlands, large quantities of seafood, tons of vegetables, fish, chicken, bread and frog legs are irradiated. Other countries actively involved in food irradiation include Japan, the Soviet Union, Hungary, France, Belgium, Uruguay, Czechoslovakia, and Israel.

The International Atomic Energy Agency estimates that in 1986 more than 500,000 metric tonnes of food was irradiated throughout the world.

Canada endorsed the irradiation of potatoes in 1960, onions in 1965, wheat, flour and herbs in 1969 and spices in 1984. Health and Welfare Canada is now studying a request to apply the process to poultry.

Food irradiation is a process that can safely preserve food and eliminate bacteria, insects and micro-organisms. It offers advantages over other conventional processing and additive techniques. Like pasteurization, irradiation can help ensure that our food remains wholesome and safe to eat. Properly labelled, irradiated food permits a better choice for the discriminating Canadian consumer.

Information From The Canadian Nuclear Association

This fact sheet is one of a number of fact sheets that are part of a public information program from the Canadian Nuclear Association. For more information contact:

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Canadian Nuclear Association
Association Nucléaire Canadienne

Number 9 06-1988

Reactor proposal draws ire

By KEVIN BLEVINS
Journal Staff Writer

Albertans may have a nuclear power plant on their doorstep – if Saskatchewan goes ahead with plans for building a Candu-three reactor.

A spokesman for SaskPower, Saskatchewan's public electricity utility, said Tuesday if a reactor is built – a first for Western Canada – it would probably be located in the northwest part of Saskatchewan.

It might even end up close to the Alberta border, he suggested.

But Brian Staszenski, director of the Environment Centre of Alberta, promises to fight the proposal, calling it a "step backwards."

"In Western Canada, with all our power resources, the last thing we need is a nuclear reactor," he said.

Albertans should be alarmed by the possibility of a nuclear power plant next door, he said, raising the possibility of a disaster like a meltdown or a release of nuclear wastes into the environment. Locating it near Lloydminster, which straddles the border between the two provinces and is the site of the $1.3-billion Husky heavy-oil upgrader, would be disturbing.

"So if they try to do this, I think they will see one of the biggest fights they've ever seen," he said.

Bob Rempel, spokesman for SaskPower in Regina, acknowledged environmental concerns about nuclear power, but said any type of power source affects the environment.

"With hydroelectricity, you have the change of habitat, the effects on wildlife. With coal-fired plants, there are the arguments about the greenhouse effect and acid-rain... But when you look at what's been done in Ontario, I think nuclear power has come a long way."

Ontario, New Brunswick and Quebec are the only Canadian provinces with nuclear power plants.

Saskatchewan has coal-fired plants in the southeast, hydroelectric plants in the northeast and southwest, but there isn't a major power plant in the northwest, Rempel said.

"No one's looking at any specific spot. We're not that far yet. But the northwest, north-central part of the province would certainly be high on the list."

An even greater factor in determining the reactor's location may be the Husky upgrader in Lloydminster, slated to begin operation in 1992.

It would be logical and economical to build a new power plant near a large industrial consumer like the upgrader, which will use electricity equivalent to that of a city of 30,000, Rempel said.

Greg Barnes, the manager of engineering for the upgrader, said the reliable source of electricity a nuclear reactor would provide is welcomed.[1]

Alberta wary of Sask. nuclear project

By ED STRUZIK
and KEVIN BLEVINS
Journal Staff Writers

Alberta doesn't want a nuclear power plant near the Saskatchewan border, nor anywhere else in that province, says Environment Minister Ian Reid.

Reid was commenting Wednesday on a plan by SaskPower to buy power from a privately owned nuclear-power plant that is being proposed for the northwest part of the province or possibly around Lloydminster.

"I'm not at all sure that it's necessary to be considering atomic generation in western Canada at any location," Reid said.

"We may have uranium mines, but we have a large amount of coal and there is still the potential for electric power in northern Manitoba, maybe even in the Slave River in Alberta," he said.

In fact, said Transportation and Utilities Minister Al Adair, nuclear power in Alberta is "not even an option."

Reid said Saskatchewan wouldn't necessarily have to consult with Alberta about building the reactor because it's a matter of federal jurisdiction.

But the potential for radioactive accidents, and the problems of disposing of nuclear waste safely are still major concerns, Adair said Wednesday.

Adair said the provincial government will continue to support the use of coal-fired plants as Alberta's main generator of electricity.

A spokesman for SaskPower, Saskatchewan's public electrical utility, said Tuesday an approval in principle has been reached between SaskPower and a private company to build a nuclear power plant in Saskatchewan, possibly near the Alberta border.

Bob Rempel, a spokesman for SaskPower, confirmed Tuesday that a plan has been approved in principle to allow a 450-megawatt, Candu-three reactor to be built by Atomic Energy of Canada Ltd., and owned by Western Project Development Associates.[2]

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[1] *The Edmonton Journal* for the article by Kevin Blevins, taken from February 8, 1989, p. B1 issue. Reprinted with permission of *The Edmonton Journal*.

[2] *The Edmonton Journal* for the article by Ed Struzik and Kevin Blevins, taken from February 9, 1989, p. B1 issue. Reprinted with permission of *The Edmonton Journal*.

Nuclear reactor option defended

By KEVIN BLEVINS
Journal Staff Writer

A University of Calgary physics professor says Albertans shouldn't be too alarmed by the possibility of having a nuclear reactor next door, in Saskatchewan.

"In the next 30 years, the problems of carbon dioxide and its effects on the atmosphere are, in my opinion, (going to be) far greater than those of nuclear waste," Harvey Buckmaster said Wednesday.

Buckmaster was referring to worldwide concerns that too much carbon dioxide in the atmosphere is warming the earth's climate to dangerously high levels.

Reid says no thanks B1

Carbon dioxide is released when coal is burned. Buckmaster has been studying the effects of carbon dioxide on the atmosphere for the last 10 years.

The latest available statistics from the United Nations show that Canada produced the fourth highest amount of carbon dioxide per capita in the world in 1986, Buckmaster said.

SaskPower, Saskatchewan's public electricity utility, is considering participating in a plan to buy power from a privately owned, Candu-three reactor, which would be built in Saskatchewan.

SaskPower officials have suggested that if the reactor is built, it would probably be in the northwestern part of the province, possibly near the Alberta border.

That worries the Environment Centre of Alberta and the provincial government.

But Buckmaster says the nuclear option is not a bad one because Saskatchewan uses lignite coal for its coal-fired plants – a coal that emits the most carbon dioxide when burned.

"If you closed down the Estevan coal-fired plant (Boundary Dam) in Saskatchewan, and replaced it with a nuclear one, you'd probably be making an environmental advancement," he contended.

"Anti-nuclear activists often forget that the Candu reactors are by far the safest in the world. With their technology, a Chernobyl is an impossibility."

The world's worst nuclear accident occurred in 1986 when the Chernobyl plant exploded in the Soviet Union, killing 31 people and causing acute radiation sickness in 237 others.

In Alberta, with its vast coal and natural gas resources, nuclear energy isn't needed, Buckmaster says.

But he would like to see existing coal-fired plants converted to natural gas because the carbon dioxide emitted from methane is significantly less than that emitted from coal.

However, Energy Minister Neil Webber says any such conversion is unlikely.

"I know they are converting coal-generation plants to natural gas in California, but when you look at pollution in Los Angeles and Alberta, there's no comparison," he said. "We don't have that kind of pollution problem."

In general, Alberta's environmental standards for industry are among the strictest in North America, he added.[1]

Use of nuclear reactors to extract heavy oil studied

RICK PEDERSEN
Journal Staff Writer
Edmonton

Nuclear reactors will be used in the Alberta oilpatch eventually as non-renewable fuels like natural gas begin to deplete, says the chairman of the Alberta Oil Sands Technology and Research Authority.

The only question is when, Bill Yurko said Monday.

The authority has joined Atomic Energy of Canada in a study to determine if a CANDU-3 nuclear reactor could produce steam for extracting heavy oil and bitumen.

"We're each putting in $125,000."

The study will be completed in March 1994, he said, explaining that the project was unveiled recently to the House of Commons energy committee.

This is the second time around for the idea.

"We did this study 11 years ago," Yurko said, and although nuclear power was a competitive alternative in the early 1980s natural gas is still used instead.

The earlier study needs updating now, Yurko said.

High-pressure steam was required when the first study was done, but now new technologies mean low-pressure steam can do the job. This makes a nuclear reactor more suitable, he said.

But the price of natural gas has dropped sharply making this fuel even more competitive.

Once the study is complete the politicians will have to decide what to do, he said.[2]

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[1] *The Edmonton Journal* for the article by Kevin Blevins, taken from February 9, 1989, p. A18 issue. Reprinted with permission of *The Edmonton Journal.*

[2] *The Edmonton Journal* for the article by Rick Pederson, taken from March 24, 1992, p. A8 issue. Reprinted with permission of *The Edmonton Journal.*

NuclearFacts

Seeking to generate a better understanding

What are the Main Advantages of Nuclear Energy?

- **Excellent Return on Nuclear Research Investment by Government** — The most effective in the western world in terms of electricity produced per research dollar to the end of 1988.

	Electricity per US $ spent (kWh)	Total Expenditure (US $ billion)
Canada	254	2.8
U.K.	144	6.5
U.S.A.	140	33.8
France	124	14.6
Japan	112	12.6
W. Germany	86	11.9
Italy	21	4.4

- **Low Cost Electricity** — One half of Ontario electricity now comes from CANDUs which helps keep Ontario rates among the cheapest in the world.

	Residential (cents/kWh)	Large Industrial (cents/kWh)
Toronto	6.6	4.2
Detroit	11.6	7.2
London	13.0	7.2
Paris	16.2	5.8
New York City	17.3	11.3

Average Rates — November 1990

Revised Dec. 1990

When the Canadian government decided in 1955 to fund a program to develop nuclear energy it did so in the knowledge that, in certain parts of the country, there would be an early need to augment hydro potential for the production of electricity.

For Ontario, which lacked fossil fuel deposits, the possibility of developing a use for the uranium deposits at Elliott Lake appeared to be an attractive alternative which might prove economical compared with the alternative of importing coal from the United States. These early expectations have been met, not only in economic terms, but also in terms of worker and public safety and environmental impact of nuclear power compared with alternative energy sources for electricity production.

Economical Option

In Ontario, nuclear power has proven to be an economical choice for meeting half of existing electricity demand.

Hydraulic power remains the lowest cost supply on the Ontario system but there is limited potential for further development. The cost per kilowatthour (and proportion) of the three supply sources in 1990 were hydraulic 0.95 cents (29.6%), nuclear 4.2 cents (48.1%) and fossil 4.6 cents (22.3%).

An independent Nuclear Cost Review recently reported to the Ontario government that Ontario Hydro's nuclear cost estimates are accurate and its method of cost comparison with alternatives is appropriate.

Reactors Operated Safely

Dr. Kenneth Hare, a world renowned climatologist and environmentalist headed a year long study into the safety of Ontario's nuclear power reactors. In his report, submitted in February 1988, Dr. Hare concluded: "The Ontario Hydro reactors are being operated safely and at high standards of technical performance. No significant adverse impact has been detected in either the workforce or the public. The risk of accidents serious enough to affect the public adversely can never be zero, but is very remote."

In 30 years of experience, no nuclear plant worker in Canada has lost time from the job as a reseult of exposure to radiation.

Better Option for the Environment

Urban smog, acid rain and global warming are all caused by the consumption of fossil fuels in power plants, factories, homes and automobiles.

In response to the concern related to global warming, the 1988 International Conference on the Changing Environment, held in Toronto, called for a 20 percent reduction in carbon dioxide emissions by 2005. Studies have now shown that this target cannot be met by conservation and energy efficiency measures alone and that, as the Toronto conference also suggested, half of such a reduction would have to come from modification in energy supply.

Nuclear power plants do not emit acid gases nor carbon dioxide. Canada could meet half of a 20 percent reduction by phasing out fossil-fired generating stations and replacing them with nuclear plants. This is well within the capability of the nuclear supply sector.

The gradual substitution of nuclear

electricity for direct use of fossil fuels could also lead to further improvements in overall energy efficiency and in reduction of airborne pollution.

Nuclear Waste Managed Safely

For 30 years the high level radioactive wastes have been stored in pools of water. The water protects plant workers by effectively shielding the radiation. It also removes heat being generated as the level of radioactivity in the wastes rapidly diminishes.

After about 5 years the used fuel bundles can be removed from the pools and stored in dry, above-ground, concrete canisters. The canisters, which do not require a cooling system, have been used for about 15 years and are currently in use at sites in Manitoba, Ontario and Quebec.

For the longer term a multi-barrier deep disposal concept has been developed. Following more than 10 years of research, including work in a specially constructed underground laboratory, Canadian scientists are confident they can emulate nature by sealing the wastes deep in the earth's crust. Natural uranium deposits have been found where the ore has not leached the site despite the presence of ground water. The disposal concept is being put forward for public review by an independent panel which has already been appointed under the Federal Environmental Assessment Review Office.

As the federal government concluded in its 1988 response to a Standing Committee report on Nuclear Wastes: "In many respects, the nuclear industry in Canada is a pioneer to be emulated in its responsible approach to managing its used fuel in both the near and the long term." Indeed the nuclear industry regards the safe retention and management of its wastes as the major environmental advantage of nuclear power.

Electricity consumers in New Brunswick, Ontario and Quebec contribute, as part of their electricity bill, to a fund adequate to manage and dispose of wastes and to completely dismantle the nuclear reactors at the end of their service life.

Strictly Regulated

The nuclear industry is strictly regulated to protect workers and the public.

Construction and operating licences must be obtained from the Atomic Energy Control Board for all uranium mines, nuclear reactors, etc.

The Board ensures conformity with its regulations by having inspectors resident on-site at nuclear stations and has the power to suspend or cancel licences if regulations are breached or an operator fails to comply with instructions from the Board.

No Resource Constraints

Known reserves of uranium are sufficient to fuel existing and planned reactors for many decades. New reserves will be added when the price of uranium rises to the point where exploration is resumed. Thorium, which is three times more abundant in nature as uranium could also be used in a CANDU type reactor. The used fuel can be recycled to produce up to 60 times as much electricity as a single pass through a reactor. There are, therefore, no resource constraints to the continued and further use of CANDU reactors.

The environmental case for nuclear power

	Coal	Nuclear
	1,000 Megawatt station	**1,000 Megawatt station**
Land use (in hectares)	70	20
Fuel use (in tons per year)	2 500 000	125
Wastes (in 000's of tons per year)	Ash 600 Carbon dioxide 6,000 Sulfur dioxide 100 Nitrous oxide 16	Used fuel .125 Mine tailings 25

The environmental case for nuclear power.

Information from the Canadian Nuclear Association
This fact sheet is one of a number of fact sheets that are part of a public information program from the Canadian Nuclear Association.
For more information contact:

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A nuclear Alberta?

On the face of it, trying to interest Alberta in a nuclear industry seems a bit like trying to persuade Florida to import grapefruits. When it comes to energy, Alberta is in a surplus position.

There are also the questions of environmental and human safety that continue to surround the nuclear industry. Atomic Energy of Canada Ltd., the Crown corporation that builds and markets Candu reactors, has insisted for decades that its reactors are as safe as any in the world, if not safer, but large segments of the population remain unconvinced.

Three Mile Island, Chernobyl and a number of lesser nuclear accidents have left their impact on the public mind. Just this week, while AECL was promoting its nuclear plans to Alberta, Russian scientists were contending with a radioactive leak at a plant near St. Petersburg – different make of plant, of course, but a nuclear plant. Does Alberta, so rich in other energy sources, need this aggravation?

AECL, of course, badly needs the business. For all the federal investment in research over the years, and the worldwide marketing, the federal corporation has not managed many foreign sales. With Ottawa scaling back its funding, AECL has turned determinedly to the provinces for support. Here, too, it has had mixed success. Ontario Hydro largely runs its own nuclear show. The former Saskatchewan government of Grant Devine agreed to a research and development program with AECL, but the province's new NDP government has let the agreement lapse. Which now brings AECL to Alberta.

The AECL offer to Alberta is apparently similar to the one made to Saskatchewan – a research program aimed at the building of Candu 3 reactors. There is a special wrinkle in Alberta because of the potential for using a Candu reactor to supply the steam for extracting oil from the province's oil sands – a mixing of energy technologies, in other words.

You can entertain the suspicion that AECL is happy to play one province against the other in hopes of forcing a deal. If that is the case, it is having some success – in Saskatchewan at least. Having let Saskatchewan's agreement lapse, NDP Premier Roy Romanow is now doing a bit of backpedalling. Saskatchewan, he suggests, would be happy to sign a research deal so long as it doesn't involve actual reactor construction. Alberta could take that. It is hard to image a worse form of provincial – truly provincial – competition.

Alberta, quite rightly, is reacting with some skepticism. This is a province with a 50-year supply of natural gas and a 200-year supply of coal, both of which are in direct competition with nuclear power as energy sources. Natural gas at present has advantages of being inexpensive and of being perceived to be safer than nuclear power. This is not a ripe market, in other words, for nuclear power. Energy Minister Rick Orman says he has conveyed as much to AECL salespeople.

There remains the question of nuclear technology in the oil sands. An Alberta agency is helping to fund a feasibility study, and has looked at the question off and on for the past decade. Research is always valuable – so long as this research doesn't become the means for introducing a nuclear energy without the prior say of the people of Alberta.

Given the enduring question of safety, and Alberta's wealth of other energy sources, the province should not consider nuclear energy before it has openly consulted the people. Research programs should be fully disclosed. And we should keep in mind that it will be decades before the gas runs out.[1]

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[1] *The Edmonton Journal* for the editorial, taken from March 25, 1992, p. A10 issue. Reprinted with permission of *The Edmonton Journal*.

NOTES

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Physics 30

Student Module Booklet

Module 8

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